Container terminal hinterland characterization in the Portuguese port system

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ABSTRACT:

As the dynamic of the world economy changed over the last decades, nowadays the economic influence of a seaport depends not only on the distance, but mainly on the effectiveness of its inland connections. In order to improve the competition level of a seaport, intermodal transport is being used to make the best of the transportation infrastructure, giving more route options and lowering travel costs by selecting optimum carrier and vehicle combinations for each case. However, it is necessary to compare the intermodal option with road only transportation in regards of the price, travel time and in how this choice helps improve the hinterland of the port itself.

In this context, a hinterland characterization of the Portuguese container terminals of Leixões (TCL), Lisbon (Liscont and Sotagus), Setúbal (Sadoport) and Sines (Terminal XXI) was made using a Geographic Information System (GIS) tool, which allows a good visualization of the impact intermodal transport has in the inland influence of a port. The hinterland of these terminals were analyzed using a software developed in CENTEC (Intermodal Analyst), with regard to the transportation cost, transportation time and generalized transportation cost considering two scenarios, the first one with road only transportation and the second one adding an intermodal option to the port of Sines.

The results of this study proved that intermodalism can help improve the inland influence of a seaport only in locations far from the terminal, as the combination of rail and road transport gets more competitive for longer distances in terms of cost. At the same time, it is also important to consider that the transportation time is higher for intermodal options when compared to road only transport.

Keywords:

Geographic information systems, Intermodality, Transport networks, Logistics, Road transport, Rail transport.

RESUMO:

As mudanças ocorridas nas últimas décadas na dinâmica da economia mundial fizeram com que a influência econômica de um porto marítimo não dependesse mais somente das distâncias, mas principalmente da efetividade de suas conexões terrestres. De modo a aumentar a competitividade de um terminal, o transporte intermodal vem sendo utilizado de modo a se aproveitar ao máximo a infraestrutura de transportes existente, oferecendo mais opções de rotas e diminuindo os custos de transporte através da seleção da melhor combinação modal para cada caso. No entanto, é preciso comparar o transporte intermodal com o rodoviário em termos de custos, tempo de transporte e no impacto dessa escolha na região de influência do porto analisado.

Neste contexto, uma análise dos territórios de influência dos portos portugueses de Leixões (TCL), Lisboa (Liscont e Sotagus), Setúbal (Sadoport) e Sines (Terminal XXI) foi feita utilizando uma ferramenta de Sistema de Informação Geográfica, permitindo uma boa visualização do impacto que o transporte intermodal tem na área de influência de um terminal marítimo. A análise das regiões de influência dos portos foi feita utilizando um software desenvolvido no CENTEC (Intermodal Analyst), utilizando com base nos custos de transporte, no tempo de transporte e no custo generalizado de transporte considerando dois cenários, o primeiro deles somente com transporte rodoviário e o segundo com uma opção intermodal somente para o porto de Sines.

Os resultados deste estudo comprovam que o transporte intermodal pode ser um aliado para aumentar a influência de um porto em regiões distantes a ele, uma vez que a combinação de meios rodoviários e ferroviários ganha vantagem competitiva para maiores distâncias. Ao mesmo tempo, é importante levar em consideração que o tempo de transporte para opções intermodais será maior do que em casos onde somente o transporte rodoviário é utilizado.

Palavras-chave:

Sistemas de Informação Geográfica, Intermodalidade, Rede de Transportes, Logística, Transporte Rodoviário, Transporte Ferroviário

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ACRONYMS:

CAD: Computer Aided Design

DBMS: Data Base Management System

DEA: Data Envelopment Analysis

DMU: Decision Making Units

FEU: Forty-Feet Unit

GIS: Geographic Information System

GTC: Generalized Transportation Cost

IFDDS: Intermodal Framework Decision Support System

LAMBIT: Location Analysis Model for Belgian Intermodal Terminals

NUTS: Nomenclature of Territorial Units for Statistics

Ro-Ro: Roll On–Roll Off

RMG: Rail Mounted Gantry Crane

RSS: Remote Sensing System

RTG: Rubber Tyred Gantry Crane

TEU: Twenty-Foot Equivalent Unit

1. INTRODUCTION

1.1 Background and Motivation

As intermodal freight transport gains importance over the last decades because of the containerization process that the world economy went through, distance is no longer considered the parameter that better reflects the economic influence of a seaport on land and became only one of the factors to be analyzed. The effectiveness of the port's inland connections is now of great importance and intermodalism is an alternative to enhance this characteristic (Ferrari et al., 2011).

Intermodal transportation is described as the combination of at least two modes of transport (mainly road, rail and water) to move goods in the same loading unit and it gets growing recognition from policy makers, practionners and academics as an important alternative to solve the congestion and it is also, in most cases, more environmentally friendly than unimodal road transportation for the carriage of goods. In this sense, the European Commission encourages through their latest White Paper the efficient use of co-modality, shifting road freight to more environmentally friendly modes such as rail and waterborne transport in order to reduce transport-related greenhouse emissions. An important objective of the Commission therefore is to increase the share of intermodal rail and barge transport through an efficient use of co-modality. Regarding long distance transport, more than 50% of road freight should shift to more environmentally friendly modes such as rail and waterborne transport. But also on shorter distances intermodal transport can prove to be cheaper in certain cases, decreasing the external effects caused by freight transport (Meers et al., 2014).

Intermodalism is a tool of inestimable value to shippers which has given them greater choice of routings and a technique to lower costs by enabling them to select carrier combination and vehicles which offer most efficient service at least expense (Chanda, 2004). However, combined transport must still demonstrate that it can compete with road transport and this option might be successful because of reliability and the possibility to massify flows. Despite being an option to enhance the port's hinterland connections and also more sustainable than road-only transport, it can be argued that the price remains, quite often, the critical factor to be studied before adopting intermodal hinterland transport (Frémont et al., 2010). Also, successful intermodal transport also requires a conducive administrative and legal environment, and interchange of information. Also, one of the main keys to intermodalism in a transfer between modes is coordination amongst multiple freight transportation providers (Chanda, 2004).

In the context of modal change, Geographic Information System (GIS), as a spatial information system, can represent realistically the geometry of transportation networks and is used to model hinterland intermodal transportation (Deloukas et al., 1997). GIS tools are intended to support policy makers in evaluating the impact of technological, infrastructural or legislative actions as well as freight transportation during the choice of paths and transport modes, by analyzing and comparing the adoption of the aforementioned actions in different scenarios (Gianpiero et al., 2015).

Nowadays GIS applications are used by transportation analysts and decision makers in order to evaluate the adoption of measures at different levels of the logistic chain: infrastructure planning, traffic analysis, transportation safety analysis, environmental impacts assessment, etc. One of the main advantages that GIS provides is to offer a platform for managing information sharing among various actors in the transport decision making process. GIS enables a continuous analysis and revision of plans, at any point in the process: the inputs received by different stakeholders pertaining to the process can be easily integrated by also providing an advantage for analysis and presentation of the results (Gianpiero et al., 2015).

Traditionally, GIS has been applied to two-dimensional analysis on strictly spatial data. Such applications include traditional urban planning and mapping, particularly demographic data, marketing, and real estate analysis. In additional, usage in natural sciences and water and environmental engineering has become norm (Standifer et al., 2000). As for transport planning, the main use of GIS is data collection, management and display of model inputs and outputs and it requires high quality of the data (Berglund, 2001).

In order to reduce the use of road-only transport, the location of intermodal terminals, where the transshipment of goods take place, and the density of the terminal network are crucial factors to be analyzed. This location analysis can be efficiently done using GIS tools, which are composed of different transport networks, locations of terminals and their associated costs, and allows the user to make ex-ante and ex-post analysis of policy measures to stimulate the intermodal transport market. This way, GIS and transport modelling are closely related, as it is capable of capturing, management, analysis and visualization of spatial data (Macharis et al., 2009).

An important application of GIS in Europe is the location analysis model for Belgian intermodal terminals (LAMBIT), which is scaled on the Belgian intermodal network and analyzes the potential market area of a new terminal and assesses the impacts on existing terminals. The LAMBIT also compares barge/road and rail/road intermodal chains to unimodal road transport within Belgium (Macharis et al., 2011).

1.2 Objectives

Considering the increasing relevance of intermodalism in the port hinterland connections and the importance of Geographic Information Systems (GIS) tools to model transportation networks, this thesis will review the literature on container port and terminal delimitation, in which the Portuguese port system is to be analyzed and existing models of hinterlands for containerized cargo are to be described.

A software for calculating transportation costs, transit times and generalized cost of transportation, for containerized cargo in the Portuguese hinterland and cross border Spanish provinces, is to be used and its results analyzed.

Finally, a GIS tool is to be used to display the results of the models (transit times, transportation costs, generalized cost, hinterland contestability, cost reductions offered by intermodalism) per Portuguese municipality and Spanish comarca.

1.3 Structure of the Thesis

This thesis is organized in six chapters and respective appendices. Chapter 1 is the introduction of the topic to be discussed, the related background and including the goals and structure of the work.

Chapter 2 contains the literature review, with an overview on the current scenario regarding intermodal freight transportation, focusing on the advantages and disadvantages of a combined transportation mode and how it affects a port's hinterland. This chapter also describes the Geographic Information System (GIS) and its applications related to the transportation analysis of a container terminal hinterland.

Chapter 3 details the logistic infrastructure in Portugal, describing the main Portuguese ports, multimodal terminals and also the road and rail transportation network in the country.

Chapter 4 shows the results regarding the Geographic Information Systems (GIS) applications to a container terminal hinterland analysis. In this chapter, the geographic region model of Portugal and Spain used in the analysis is described, along with a description of the Intermodal Analyst Software, which provided all data used in this thesis, and also of QGIS, which is the GIS tool used in the analysis.

Chapter 5 contains the application of GIS to a hinterland analysis in Portugal, comparing road only and multimodal transportation, and all results obtained are shown.

Finally, chapter 6 presents the conclusions of this thesis and recommendations for further work.

2. LITERATURE REVIEW

2.1 Intermodal Freight Transportation

In the present competitive environment of ports, the key determinant in port competition is the ability of a port to be integrated into the local maritime and hinterland transportation chain. Creating effective integrated hinterland chains requires the coordination of several actors both in port and the hinterland (Franc et al., 2010). The term hinterland often refers to the effective market or the geo-economic space in which the seaport sells its services (Bergqvist et al., 2015).

The concept of port hinterland deeply evolved over the years following the transformations that occurred in the maritime transport industry. A hinterland is the inland area from where a port produces the majority of its businesses. Concretely, the catchment area of a port is the scatter of inland points of cargo origin/destination generating the traffic flows passing through a specific port. In abstract terms, the traditional concept of hinterland conceives it as the area whose contour is a continuous line bounding the port economic influence on shore (Ferrari et al., 2011). On the other hand, the containerization process and the development of intermodal transport networks have led to a competitive scenario in the port sector and have modified their hinterlands all over the world. Those hinterlands are no longer captive areas of one port but competitive areas among two or more ports. The hinterlands of the port of Rio Grande, in Brazil, is shown in Figure 1 (Pizzolato et al., 2010).

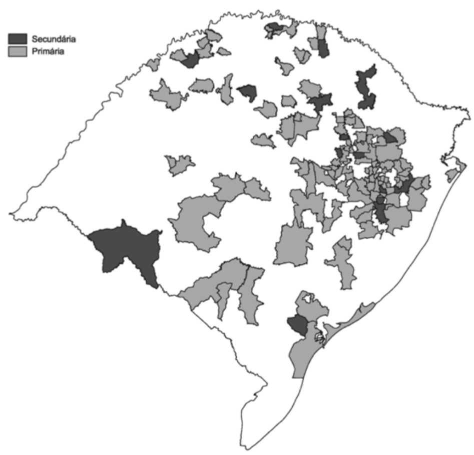


Figure 1: Hinterlands of the port of Rio Grande, Brazil – Pizzolato et al., 2010

A port hinterland is also interconnected to its foreland, which was first defined about 50 years ago, described as the land area which lied on the seaward side of a port, beyond maritime space, and with which the port was connected by ocean carriers. Also, later definitions treated foreland as overseas area with which the port carried out trade. The strong interdependency between a port's foreland and hinterland is very apparent when considering the rise of containerization and intermodality. Increased supply chain integration has made that the separation of foreland and hinterland relationships of a port into two neatly labeled packages representing dichotomy that is been questioned. The limits of the hinterland and the characteristics of the foreland are in effect interdependent variables which cannot be separated (Rodrigue et al., 2010).

While the ports drive the development to some degree, they are in partnership with terminal operating companies, the ports holding only minority share-holdings. The level of service integration is likewise fairly low, as it is the rail companies rather than the terminals that deal with the shippers and plan container flows. The terminal itself is merely an interchange location rather than the director of container movements (Monios, 2011). Having said that, nowadays not only the distance, but mainly the effectiveness of inland connections, reflects the influence of a seaport on land. Thus, the penetration capacity in the hinterland became a crucial factor in inter-port competition (Ferrari et al., 2011).

It is possible to identify that port volumes are sensitive to port efficiency as well as the effectiveness of hinterland connections. It is also important to have a geographical detail of the area within the port, as the market shares of the ports and size of the changes in market shares, due to policy measures, differ strongly by zone of origin and destination (Zondag et al., 2010). The delimitation of a container terminal potential hinterland is sensitive to infrastructure characteristics, geographical distances, availability of intermodal solutions, transportation costs, container handling costs, congestion (time in seaport), storage costs and the value of cargo (Santos et al., 2019).

Port hinterland services mostly rely on road transport in Europe. However, the enduring growth in port traffic is challenging the dominance of road for hinterland services because of costs, congestion and growing environmental constraints. For hinterland transportation high volumes are achieved by using rail-road or waterway-road transport. The ability of transport operators to attract freight from the hinterland at the lowest possible cost and with reliable and regular services is an essential condition for them to gain or maintain an advantage in a competitive environment (Frémont et al., 2010).

The increasing importance of intermodal hinterland networks for the competitive position of ports has urged port authorities to become active in the hinterland. Barcelona is one of the leading port authorities in this respect, and its strategy and the consequent active involvement in the hinterland has had a significant impact on attracting container volumes from distant hinterlands and improving the accessibility of the port (Van den Berg et al., 2011).

Combined transport can lead to the growth of maritime traffic flow in North European seaports as long as its price is lower than that of road transport (prices must be between 10% and 20% cheaper). The competitiveness of combined transport compared with road transport is due to the commercial policy of combined transport operators (Frémont et al., 2010). To identify a transport flow with the potential for a modal shift from unimodal road transport to intermodal barge transport, it is necessary to analyze the container volumes currently transported by road transport, the prices of unimodal road transport and their intermodal alternative, the time required for the post-haul transport and the type of goods transported. Short post-haulage distances are a key for the competitiveness of intermodal transport (Meers et al., 2015). An example of intermodal transport chain is represented in Figure 2 (Macharis et al., 2009).

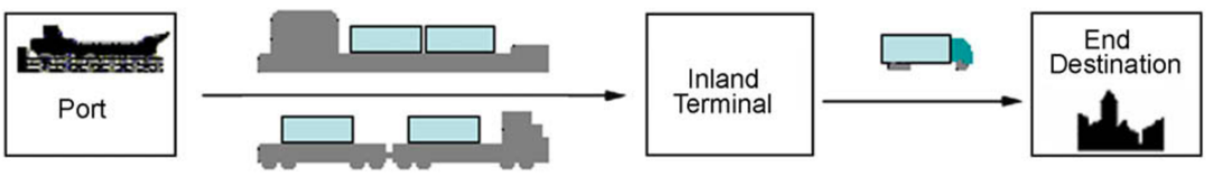


Figure 2: Intermodal transport chain – Macharis et al. 2009

An increase in fuel price potentialize the market areas of intermodal terminals. An interesting situation for intermodal transport is created when the fuel price increases, making the break-even distance smaller due to the stronger price advantage for intermodal transport on the long haul (Macharis et al., 2010). Figure 3 compares an intermodal cost structure to a road only cost structure, showing the break-even distance, where intermodal and road only transports have the same cost (Macharis et al., 2009). When the value of time is taken into consideration to compare intermodal transport and road transport costs, it is possible to see that the types of goods in the containers have an important impact. If we have lower values of time for lower value goods, intermodal transport is more competitive than road only transport (Pekin et al., 2013).

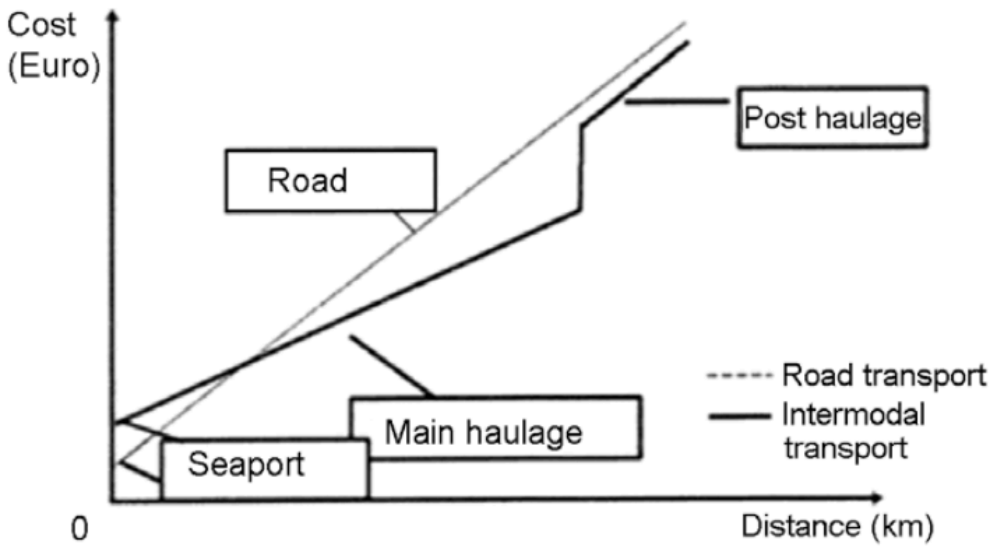


Figure 3: Intermodal cost structure – Macharis et al., 2009

In order to increase intermodal transport in short-distance hinterland container transport, it is necessary to provide daily services at a competitive price, providing more reliable services than road transport. Additional efforts should be made to correctly inform decision-makers on the available intermodal services (Meers et al., 2017). The variables used in the selection of the optimal terminal locations will severely impact the location choice. This way, depending on the perspective that is central in the decision making, different variables should be used and different terminal locations shall be given (Meers et al., 2014).

It is important to mention that intermodal containerized service is more beneficial to regions with a large economic base (Lim et al., 2008), because even though it promotes a decentralization of economic activities by evening out accessibilities to export gateways, it is not capable of erasing the logistical disadvantages of geographic peripherality (Thill et al., 2010). Also, lower generalized transport costs result in a better regional access but not always induce a higher growth in peripherical regions, as reducing the average transport cost might deepen employment and income regional inequalities (Combes et al., 2003).

Intermodalism is also a way to improve the sustainability of a port hinterland transport system. In order to do that, the best alternatives are additional port dues, where a differentiated port due system would enable better opportunities for traffic allocation of different modes of transport, and road pricing, whereby road transport is charged per kilometer driven, decreasing road traffic volume. The least preferred option is to establish a modal split quota (Bergqvist et al., 2015).

Together with the increase in intermodal hinterland transport, the concept of dry port also works to increase the sustainability of the operation. A dry port is an inland intermodal terminal directly connected to seaport(s) with high capacity transport mean(s), where customers can leave/pick up their standardized units as if directly to a seaport. Besides the general benefits to the ecological environment and the quality of life by shifting flows from road to rail, the dry port concept mainly offers seaports the possibility of securing a market in the hinterland, increasing the throughput without physical port expansion as well as better services to shippers and transport operators. The seaport cities, and also often the port authority, benefit from less road congestion and/or less need for infrastructure investments (Roso et al., 2009).

2.2 Geographic Information Systems

The Geographic Information Systems (GIS) were first invented in the decade of 1950, and since then has become an essential computational tool to represent geographic realities, manipulate and store a great amount of data and simulate different scenarios. GIS is an information system prevenient from other systems, as the Computer Aided Design (CAD), Data Base Management System (DBMS) and Remote Sensing Systems (RSS), and its functioning depends on the coordination between these systems, which will help obtain, manipulate and classify all data. It is possible to say that GIS is a spatial information system that aggregates technology elements (equipments and programs), data base (images, maps, statistical data), and personnel (trained users, maintenance and technical support). The capacity to process spatial analysis is what differentiates GIS from other information systems (Dantas et al., 1997).

The first applications of GIS technologies were in Detroit (1955) and in Chicago (1956), both in the United States, and had the purpose of representing traffic flow and data storing. From the decade of 1980, the industrial and commercial growth of GIS technologies, along with the lack of resources available for research, lead to significant changes in the way GIS was used. In this context, applications capable of transforming numerical data in new information were developed, making future scenarios forecasting possible (Dantas et al., 1977).

GIS Technology, as with most computer software, has advanced dramatically. There are four basic building blocks within GIS. Data is associated with one of these blocks. First is points, single locations that describe locations such as stations. Second is arcs: lines which describe spatial paths. Third is polygons: collections of lines enclosing an area in space. The final building block is raster GIS, which creates a matrix corresponding to a user defined spatial grid. Each cell represents a square in geographic space and is given a single value, such as height in a digital elevation model (Standifer et al., 2000).

As a spatial information system, GIS is an appropriate platform integrating the geometry and topology of spatial objects with attribute data expressing metric or non-metric properties linked to the spatial objects. GIS can represent realistically the geometry of transportation networks, such as shape, distance and positional properties. It can also express topological properties as neighborhood relationships (“left-right polygon" identification), directionality (“from node-to node" identification) and connectivity (links sharing “flows"). It allows complex spatial queries (so called views) and operations, such as generalizations of land uses, aggregations of zones or polygon overlays (Deloukas et al., 1997).

Traditionally, GIS has been applied to two-dimensional analysis on strictly spatial data. Such applications include traditional urban planning and mapping, particularly demographic data, marketing, and real estate analysis. In additional, usage in natural sciences and water and environmental engineering has become norm

(Standifer et al., 2000). As for transport planning, the main use of GIS is data collection, management and display of model inputs and outputs and it requires high quality of the data (Berglund, 2001). Emerging applications of GIS in transportation (GIS-T) and intelligent transportation systems (ITS) focus on throughput rather than accessibility. To measure accessibility, the space-time accessibility measures (STAMs) reflect the benefits that individuals receive from the transportation system, also considering the location, travel velocities and individual’s daily activity schedules (Miller and WU, 2000).

In the transportation context, three classes of GIS models are relevant: Field models (representation of the continuous variation of a phenomenon over space), Discrete models (according to which discrete entities – points, lines or polygons – populate space) and Network models (represent topologically connected linear entities such as roads, rail lines or airlines (Thill, 2000). GIS is a product of increased computing power, improved database technology, and strengthened Computer Aided Design (CAD) capabilities. GIS represents the fusion of these technologies into one product designated to display, query, and manage, and manipulate spatial data (Standifer et al., 2000).

In transport planning using GIS, the inclusion of spatial effects in regression models is important, since the best results are obtained with alternative models (spatial regression models or the ones with spatial variables included) (Lopes et al., 2014). On the other hand, a simple GIS-based tool developed to allow rapid analysis of accessibility by different transport modes uses generalized cost to measure transport costs across networks including monetary and distance components. This tool allows many alternative scenarios of transport infrastructure and policies to be easily compared and tested (Ford et al., 2015).

The GIS network has two main tasks. First of all, it visualizes the real transportation network including the terminals. The second and vital characteristic of the network is its capability in serving as a database to include transport prices (Macharis et al., 2011). A GIS-based model can provide a comprehensive set of parameters dealing with policies, rail and road infrastructures, transport units, vehicles and loading systems. It also compares transport alternatives based on the current market prices for each transport mode and enables the definition of various scenarios such as the introduction of new policies/taxes or innovative hub infrastructures and policies. Another important characteristic is that GIS enables a continuous analysis and revision of plans, at any point in the process: the inputs received by different stakeholders pertaining to the process can be easily integrated by also providing an advantage for analysis and presentation of the results (Gianpiero et al., 2015).

Three core models make up the decision support system for intermodal transport policy making using GIS. The multimodal freight model NODUS constitutes the first step in the analysis of a potential policy measure and produces aggregated outputs of the various transport modes, such as their accessibility, environmental impact and share in modal split. The location analysis model for Belgian intermodal terminals (LAMBIT) model is scaled on the Belgian intermodal network and analyzes the potential market area of a new terminal and assesses the impacts on existing terminals. Finally, the SIMBA model produces detailed output related to the reliability, speed and capacity utilization of the waterway network (Macharis et al., 2011).

The GIS-based LAMBIT model, is composed of different transport networks, locations of terminals and their associated costs, makes it possible to make ex-ante and ex-post analysis of policy measures to stimulate the intermodal transport market (Macharis et al., 2009). The LAMBIT-model has been developed to analyze the market areas of intermodal terminals and potential ones. In the LAMBIT model, barge/road and rail/road intermodal chains can be compared to unimodal road transport within Belgium (Macharis et al., 2011).

A GIS-based methodology for evaluating potential locations of certain facilities can work by producing a site-specific suitability index that may be used to rank and compare the analyzed locations (Horner et al., 2001). In order to determine intermodal terminal locations, the input data in the GIS base are the data on the traffic network of the studied area, data defined by the urban plans, data from the statistical yearbooks and data necessary in the phase of solution assessment (Petrović et al., 2019).

Similar to the LAMBIT model, GIS can be useful in the supply chain management. Currently the supply chain management is important to the companies, mainly due to technology advances which have allowed decentralizing several logistics operations. Thus, transportation and logistics operations have become important activities to reach the companies' goals. In this context, the logistics platforms arise to give quick answers, however they must be located in strategic points to reduce costs but taking into account tangible and intangibles factors (Da Costa et al., 2012).

The methodology proposed by Da Costa et al., 2012 to locate these logistics platforms in Brazil is divided in 5 phases. First, potential locations need to be defined via a multicriteria analysis that considers proximity to roads, energy and water availability, geographical and topological characteristics, among other factors. After that, it is necessary to analyze the cost reduction prevenient from the installation of the logistics platforms in the chosen locations, considering the existing multimodal transport system infrastructure and its links, ports, road and rail terminals and flow capacity. The third phase consists on checking if the chosen locations are adequate, and if not, they must be adjusted. Finally, the results are presented and analyzed using the GIS tool developed. Figure 4 represents this logistics platforms location methodology.

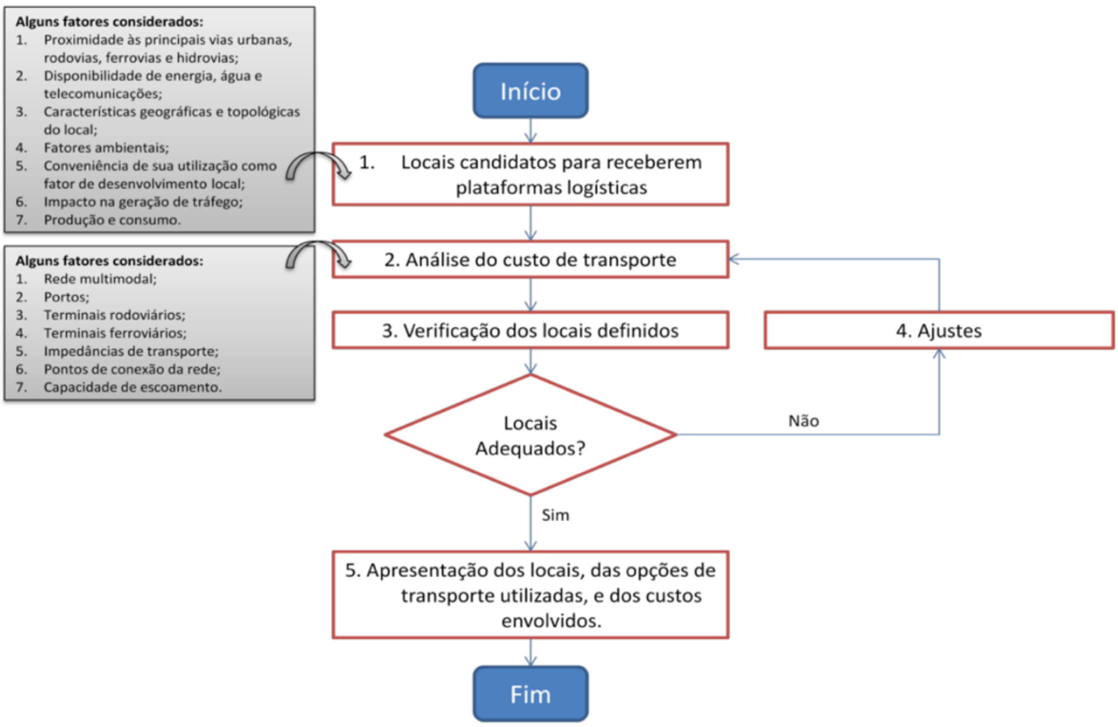


Figure 4: Logistics platforms location methodology using GIS – Da Costa et al. 2012

An application of GIS in transport planning is the Intermodal Framework Decision Support System (IFDDS). The IFDSS is a GIS-based decision support system relying on a central GIS application, communicating with different services providing a set of extended functionalities supporting intermodal routes design, analysis, comparison and sharing. The main components of the designed application are the customer needs identification module, the scenario configuration module, the route optimization module, the web based intermodal platform and the GPS based traffic data monitoring (Gianpiero et al., 2015).

The customer needs identification module is dedicated to user needs definition in order to perform the scenario analysis based on specific user requirements. The scenario configuration module supports the freight transport scenario definition, thus enabling the design of resources used in the transport chain, the freight transport flow, the transport mix, the transport resources (truck and train) and the Intermodal Transport Unit characteristics. The route optimization module is meant to calculate best routing solutions according with user defined multi-criteria optimization logics. The Web based Intermodal platform supports the setup of an intermodal community that, using the IFDSS applications, is able to provide needs, information and expertise in order to improve the intermodal transport performance. Finally, the GPS based traffic data monitoring is meant to support the integration of data provided by various traffic data collection systems and networks, in order to reliably assess the resources passing by the analyzed routes (Gianpiero et al., 2015).

Another application of GIS-based analytical tools for transport planning applied to the city of Porto Alegre, in Brazil, compares the outcomes of alternative approaches of spatial regression models with the results of traditional multiple linear regression models. Regression models, for example, are commonly used in the trip generation phase of transport planning. They are statistical tools that explore the existing relationships among two or more variables, so that one of them can be explained (and therefore its value can be estimated) by the other(s). However, in the presence of a significant spatial autocorrelation, model estimations have to consider and to incorporate the spatial structure of data. Spatial regressions, or regression analysis incorporating the existing spatial dependence of data, are likely to improve the predictive power of the regression models (Lopes et al., 2014).

The results of the application in the city of Porto Alegre indicated that the alternative models performed better than the traditional models. Therefore, the effects of spatial dependence in regression models are important and must be explicitly considered. That was observed in the models built using both 1974 and 2003 datasets (Lopes et al., 2014).

3. LOGISTIC INFRASTRUCTURE IN PORTUGAL

3.1 Portuguese ports

Portuguese ports have come to be known as the ‘Portuguese range’, comprising a set of ports located in the west coast of the Iberian Peninsula, currently serving primarily the Portuguese hinterland but also the cross-border regions of Spain and, to a lesser extent, the region of Madrid. This group of ports includes Leixões, Aveiro, Lisbon, Setúbal and Sines (main ports) but also two smaller commercial ports: Viana do Castelo and Figueira da Foz. Grouped in a multi-port gateway region, these ports are directly connected to one of the main European Union rail freight corridors and possess a natural competitive advantage as a gateway to foreland regions along the Atlantic Ocean, such as Latin America, North America and West Africa (Santos et al. 2017).

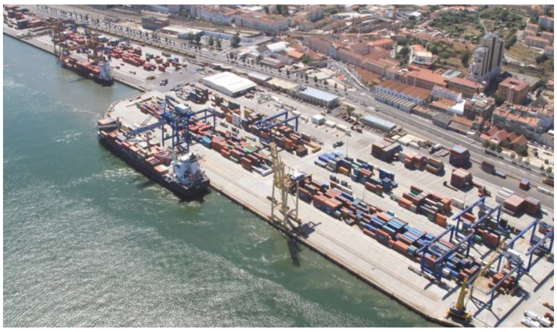
These ports include one or more container terminals per port, the most notable case being Lisbon. The main container terminals in the “Portuguese range” are Terminal XXI, located in the port of Sines; TCL, in the port of Leixões; Sadoport, located in the port of Setúbal, and finally Sotagus and Liscont, located both in the port of Lisbon. The map represented in Figure 5 shows the geographical location of the ports and terminals in the “Portuguese range” and Figure 6 shows these ports terminals for containerized cargo, except for Aveiro and Viana do Castelo.

Figure 5: Location of ports and container terminals in the “Portuguese range” (Source:Santos et al. 2019).

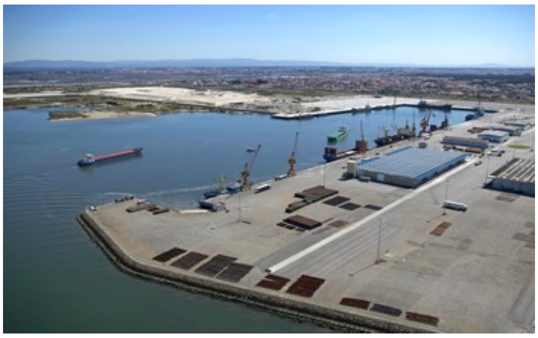
Port of Viana do Castelo – Node 633

Port of Lisbon – Liscont – Node 21

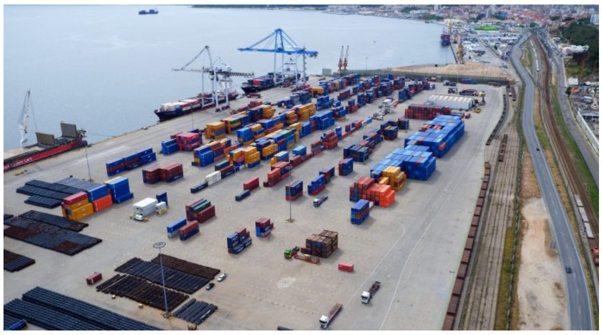
Port of Leixões – Node 544



Port of Lisbon – Sotagus – Node 17

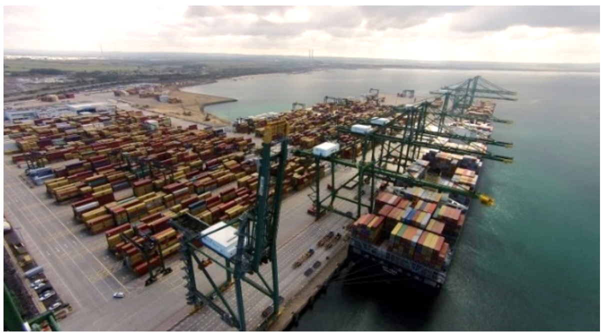


Port of Aveiro – Node 404



Port of Setúbal – Sadoport – Node 32

Port of Figueira da Foz – Node 636



Port of Sines – Terminal XXI – Node 133

Figure 6: Portuguese range container terminals (except minor ports of Aveiro and Viana do Castelo)

Figure 7 shows the number of TEU handled throughout the last 10 years, being noteworthy mentioning that Terminal XXI stands out because it is also a transshipment hub (80%) (Santos et al. 2019). Also, Table 1 shows the movement of containers in the main ports of inland Portugal in 2018, in TEUs (Twenty-foot Equivalent Units).

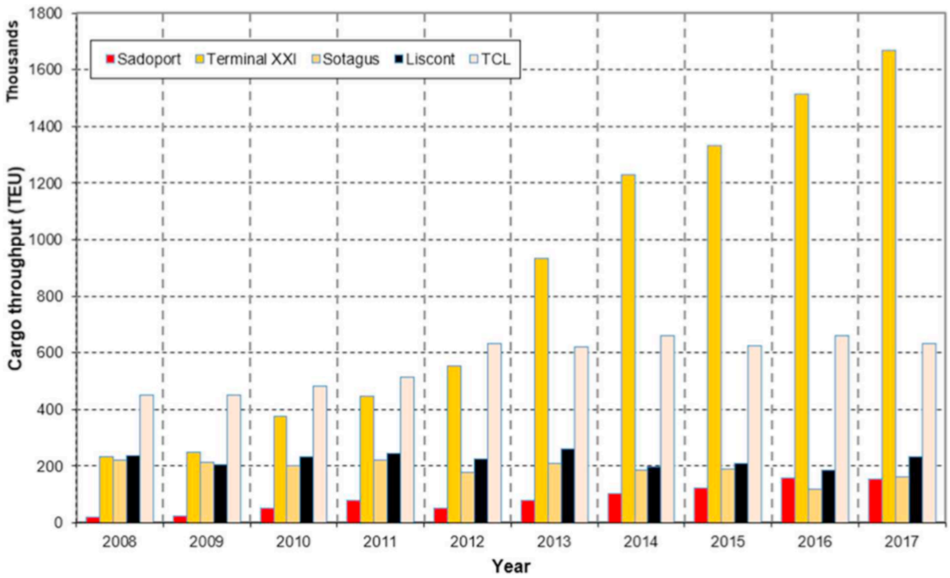


Figure 7: Container traffic in terminals 2008-2017 – Santos et al. 2019

Table 1: Container movement in the main Portuguese ports in 2018 – Administrações Portuárias/ Instituto da Mobilidade e dos Transportes, I.P.

Ports	TEU - Loading	TEU - Unloading
Viana do Castelo	233	8
Douro e Leixões	312403	355109
Aveiro	54	5
Figueira da Foz	10054	8771
Lisboa	212594	215656
Setubal	64195	59099
Sines	886353	864092
Faro	0	0
Portimão	0	0
Total	1485886	1502740

When considering the Iberian container terminals, Terminal XXI in the port of Sines and TCL - N in Leixões are the ones located in the "Portuguese range" with higher levels of efficiency, along with Alicante and Algeciras in Spain. These efficiencies were measured by the data envelopment analysis (DEA) method proposed by Charnes et al. (1978), which is developed from an application of the linear programming that transforms multiple inputs and outputs into a relative efficiency index between the compared decision making units (DMUs). Figure 8 shows the level of efficiency of container terminals in the Iberian peninsula, in which the Bilbao container terminal, in Spain, presents the lower level of efficiency (Dias et al. 2009).

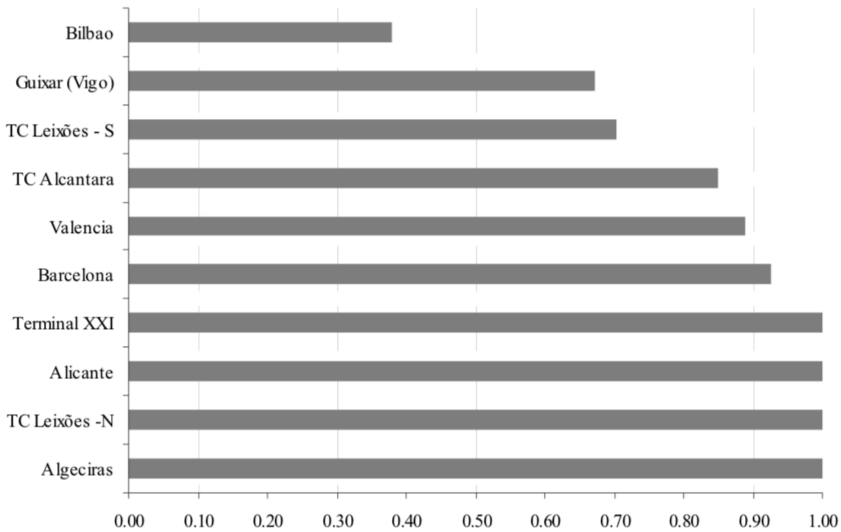


Figure 8: Efficiency level of container terminals – Dias et al. 2009

3.1.1 Port of Sines

The Port of Sines is an important transshipment hub, which is an operation largely used in the liner shipping industry. A global liner shipping company is unable to provide direct shipping services for each pair of ports because there are too many ports scattered around the world. Rather, containers can be transshipped at a port from one ship to another during their route from an origin port to a destination. Apart from expanding the scope of shipping services, the container transshipment operations also enable container consolidation at major transshipment ports. As a consequence, the liner shipping companies can benefit from economies of scale in terms of ship size, by deploying large container ships. Hence, container transshipment operations are prevalent in the liner shipping industry. All around the world, approximately 27% of container throughput consists of transshipment containers (Wang et al., 2012).

At the end of 2018, the container terminal of the Port of Sines was connected to 20 locations via regular service lines, 15 of them operated by MSC (2 of these lines shared with Maersk), 4 operated by WEC Lines and 1 operated by Hapag-Lloyd. The movement of containers in Sines from 2009 to 2018 is represented in Figure 9. It is also important to mention that the Porto of Sines is determinant for Portugal's energetic supplying, being the leading port in the handling of crude, mineral coal and LNG (Administração dos Portos de Sines e do Algarve S.A.).

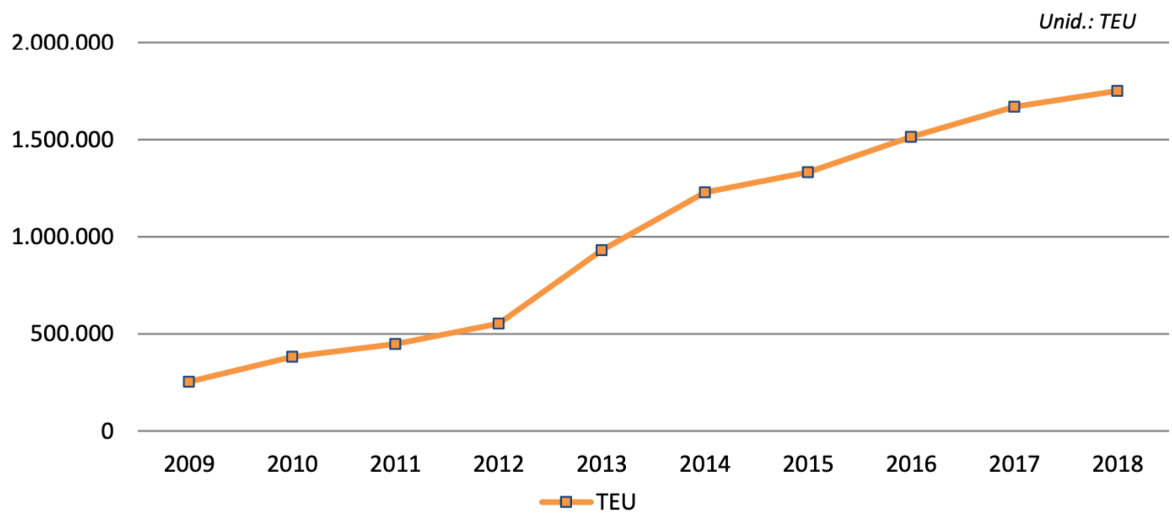


Figure 9: Movement of containers in the Port of Sines from 2009 to 2018 – Administração dos Portos de Sines e do Algarve S.A.

Located on the Southeast of Europe, 58 nautical miles south from Lisbon, the Port of Sines lays on the cross of the main international maritime routes – East-West and North-South. Its strategic location, along with its natural characteristics, allow the Port to be positioned as an important hub port in the Ibero-Atlantic front. The Port of Sines direct hinterland comprises all the south and midland part of Portugal. As far as the extended hinterland concerns, the Port of Sines has a competitive position towards the Spanish Extremadura and the area of Madrid. A map of the port's extended hinterland is represented in Figure 10 (Administração dos Portos de Sines e do Algarve S.A.).

Figure 10: Extended hinterland of the Port of Sines - Administração dos Portos de Sines e do Algarve S.A.

3.1.1.1 Terminal XXI

The Sines' Container Terminal, called Terminal XXI, started its operations in 2004 under a public service concession by the company PSA Sines - Terminais de Contentores S.A. With a staged, sustained development plan, Terminal XXI provides natural depths down to 17 meters (ZH), allowing the reception of the last generation container carriers performing intercontinental routes, as well as the concerning feeder (Administração dos Portos de Sines e do Algarve S.A.).

Presently with a quay length of 940m + 200m and 10 post-panamax and super post-panamax gantry cranes, and also 2 mobile cranes, the terminal offers a yard with 42 ha, and a total capacity of 2.300.000 TEU per year. This terminal will be the target of an expansion plan that will provide the infrastructure with a quay front of 1,950 meters (currently 1,040 meters), divided into a front of 1,750 meters and another one of 200 meters, allowing the simultaneous docking of four of the latest generation containerships and a feeder ship; the installation of 9 more “super post-panamax” cranes (the total will become 19), 30 park gantries and transport equipment; the expansion of the storage area from the current 42 to 60 hectares; and the increase in capacity from the current 2.3 million to 4.1 M TEU (Administração dos Portos de Sines e do Algarve S.A.).

3.1.2 Port of Leixões

Located in the metropolitan area of the city of Porto, the Port of Leixões serves a hinterland of 14 million people and it is the most important port in the north-west of the Iberian Peninsula. It is an indispensable infrastructure for the industries located in the north region of Portugal and is vital for their competitiveness and internationalization.

The Port of Leixões is the most important Portuguese port in terms of roll-on/roll-off movements and the second one when considering containerized cargo exportation. The movement of containers in the Port of Leixões in 2016 was 6384000 tons, which represented 34,9% of all cargo handling in the port, and in 2017 was 6184000, just about 31,7% of the total movement of cargo in Leixões. Detailed numbers of the movement of cargo in the port are shown in Table 2 and the map of the port with its terminals in Figure 11 (Administração dos Portos do Douro, Leixões e Viana do Castelo – ADPL).

Table 2: Movement of cargo in the Port of Leixões per cargo type - Administração dos Portos do Douro, Leixões e Viana do Castelo – ADPL

Sectors	2017		2016		Variation	
	1000 TON	%	1000 TON	%	1000 TON	%
Commercial Terminals	**10782**	**55,2%**	**10920**	**59,6%**	**-138**	**-1,3%**
Fractioned General Cargo	1121	5,7%	1198	6,5%	-76	-6,4%
Containerized Cargo	6184	31,7%	6384	34,9%	-200	-3,1%
Ro-Ro Cargo	1062	5,4%	902	4,9%	159	17,7%
Solid Bulk	2353	12,2%	2381	13,0%	-28	-1,2%
Liquid Bulk	61	0,3%	55	0,3%	7	12,3
Oil and Oceanic Terminals	**8734**	**44,8%**	**7395**	**40,4%**	**1339**	**18,1%**
Total	19516	100,0%	18315	100,0%	1201	6,6%

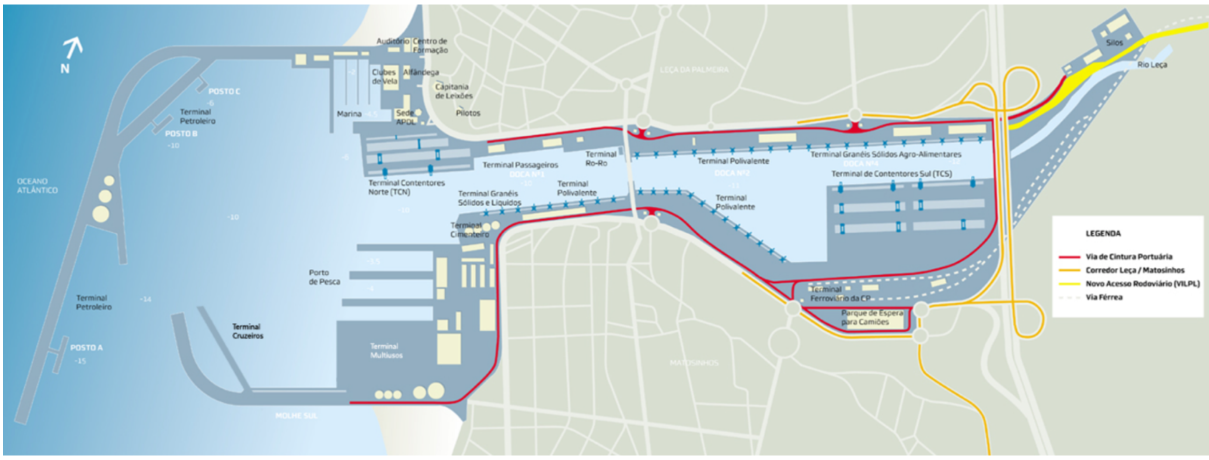


Figure 11: Map of the Port of Leixões - Administração dos Portos do Douro, Leixões e Viana do Castelo – ADPL

3.1.2.1 Leixões Container Terminal

The North and South Container Terminals in the port of Leixões are under concession to TCL - Terminal de Contentores de Leixões, S.A. and have the following characteristics:

North Container Terminal

- Berthing Quay: 360 meters long;
- Depths: -10 meters;
- Equipment: 2 quayside gantries with a capacity of up to 35/44 tons and 5 gantry cranes of 35/45 tons capacity. It also disposes of 14 semi-towages for the internal transport of containers;
- Total Area: 6 hectares;
- Storing Capacity: 4.000 TEUs (around 2.600 containers);
- Handling Capacity: 250.000 TEUs /year (around 172.800 containers);
- Reefer Containers: equipped with 96 power supply outlets.

South Container Terminal

- Berthing Quay: 540 meters long berthing quay;
- Depths: -12 meters;
- Equipment: 4 quayside gantries with a capacity of up to 40/80, 40/80, 40/68 and 35/45 tons, 8 gantry cranes, of which four with 35/45 tons capacity and four with

35/50 tons capacity, 4 reach-stackers and 6 front-lift trucks. It also disposes of 22 semi-towages for the internal transport of containers;

- Total Area: 16 hectares;
- Storing Capacity: 15.000 TEUs (around 10.000 containers);
- Handling Capacity: 350.000 TEUs/year (around 226.000 containers);
- Reefer Containers: equipped with 310 power supply outlets.

All information was provided by ADPL – Administração dos Portos do Douro e Leixões and Figure 12 shows the north container terminal of the port of Leixões.

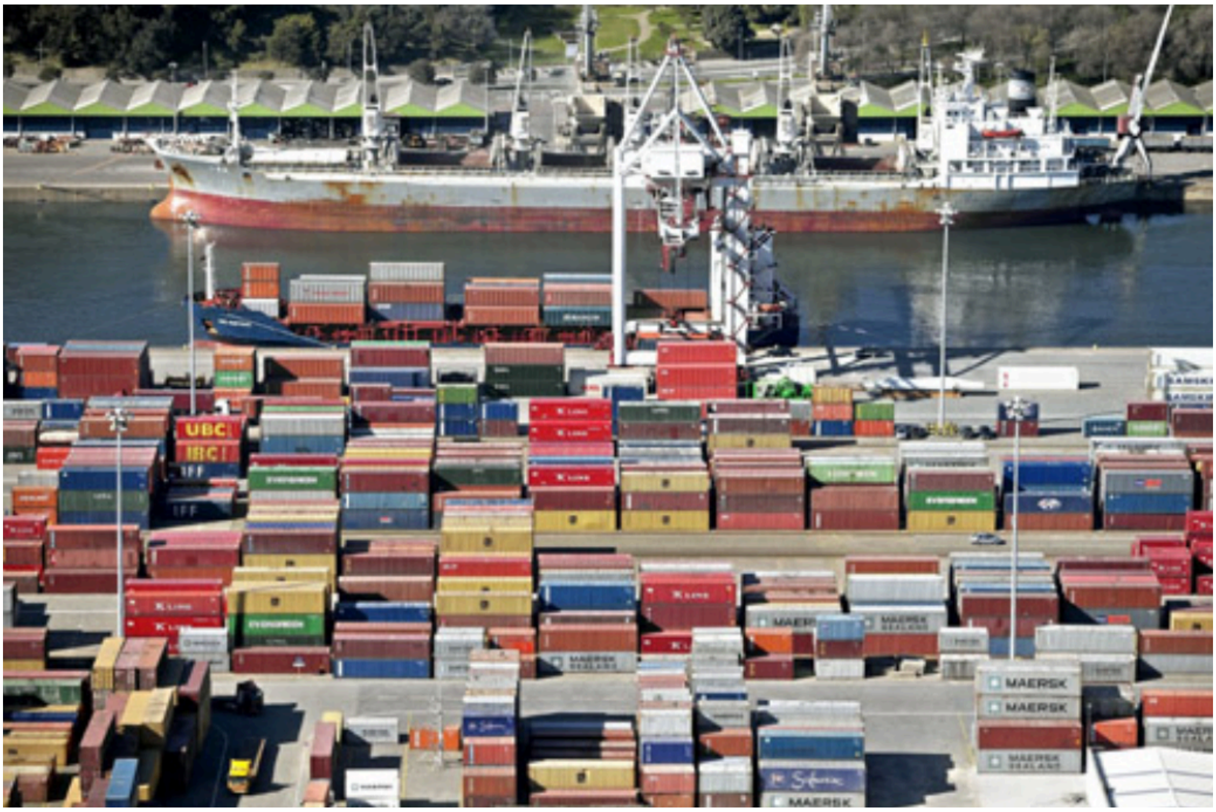


Figure 12: North container terminal of the port of Leixões

3.1.3 Port of Lisbon

Considered an important link in the connection between the Mediterranean and the North of Europe, and a strategic point for international commerce between Europe, America and Africa, the Port of Lisbon has maintained over the years its national leadership within the segment of foodstuff bulks. Port activities are developed on both banks of the river Tagus. The handling of containerized cargo, Roll-on/Roll-off and the majority of breakbulk cargo is concentrated on the northern bank. On the South bank there are various terminals specialized in liquid and solid bulk (Administração do Porto de Lisboa).

The traffic of containers is especially important to Lisbon, which has regular services of cabotage from Europe, as well as a large number of direct intercontinental services carried out by the main lines of navigation. National shipowners operate in these traffics mainly through the connections to the Azores, Madeira and PALOP's. The fact that the Port of Lisbon integrated the CSI – Container Security Initiative in January of 2006, a fact which involved the installation of non-intrusive container inspection equipment, reinforced the privileged intervention which it already carried out in commercial exchanges with the USA (Administração do Porto de Lisboa).

The movement of containerized cargo in the three terminals that do container operations in the Port of Lisbon in 2018 and 2019 is shown in Table 3 and Table 4, respectively.

Table 3: Movement of containerized cargo in the Port of Lisbon in 2018 - Administração do Porto de Lisboa

Terminal	Number of Containers	TEU	TON
Santa Apolonia Container Terminal	96545	150675	1666641
Alcantara Container Terminal	97322	140991	1536730
TML - Lisbon Multipurpose Terminal	73856	122290	1081267
Others	9241	14294	125288
Total	276964	428250	4409926

Table 4: Movement of containerized cargo in the Port of Lisbon in 2019 - Administração do Porto de Lisboa

Terminal	Number of Containers	TEU	TON
Santa Apolonia Container Terminal	118555	185885	2041326
Alcantara Container Terminal	101338	140520	1494314
TML - Lisbon Multipurpose Terminal	77161	128658	1117266
Others	5125	6577	66352
Total	302179	461640	4719258

3.1.3.1 Alcântara Container Terminal

The Alcântara Container Terminal is especially prepared for deep-sea traffic and is a privileged base in the direct connections of Europe to North, Central and South American markets, as well as the African market. It also has its own railway link which allows for efficiency earnings in traffic from/to the North of the country as well as to Galicia, the Spanish Estremadura and Andalusia. The terminal is administrated by Liscont and its main characteristics are listed below (Administração do Porto de Lisboa):

- Area of concessioned levelled ground: 97.323 square meters;
- Area of licensed levelled ground: 27.655 square meters;
- Installed handling capacity: 350.000 TEUs/Year;
- Storage Capacity: 8.400 TEUs;
- Sockets for refrigerated containers: 250;
- Length of Quay: 630m;
- Depth: -13m ZH;
- Equipment:
    - 1 Portico - Post-Panamax Dock (40 ton) and lance reach of 51m;
    - 2 Porticos - Panamax Dock (40 ton) and lance reach of 39,5m;
    - 1 mobile Gottwald crane (100 ton) and lance reach of 46m;
    - 7 Park Portico (RTG) : 40 ton;
    - 6 forklifts (16-45 tons); 4 Reach Stackers (45 ton); 17 Tractors; 19 Harnesses.

3.1.3.2 Santa Apolónia Container Terminal

This port is used for short-sea traffic and has a dedicated railway branch which is connected to the national network. The terminal is administrated by Sotagus and its main characteristics are listed below (Administração do Porto de Lisboa):

- Area of levelled ground: 164.500 square meters;
- Covered area: 2.400 square meters;
- Installed handling capacity: 450.000 TEUs/Year;
- Storage Capacity: 10.286 TEUs;
- Sockets for refrigerated containers: 200;

- Length of Quay: 292m+450m;
- Depth: between -7,3 and -8,3m / between -9 and -10m ZH;
- Equipment:
    - 2 quayside porticos - Mague: 35 tons and lance reach of 35 m;
    - 1 quayside portico- Mague: 30 tons and lance reach of 22 m;
    - 1 quayside portico: 40 tons and lance reach of 40m;
    - 1 auto crane - Gottwald: 100 tons and lance reach of 22m;
    - 7 park porticos (RTG): 35 tons;
    - 2 park porticos (RMG): 40 ton;.
    - 11 forklifts (16-40 tons); 19 Tractors (3-20', 16-40'); 16 Harnesses.

3.1.4. Port of Setúbal

The Port of Setúbal is made up of several specialized terminals that render public services in the various types of cargo. The port is composed by 2 multipurpose terminals, on roll-on roll off terminal and another 2 terminals for solid and liquid bulks. The cargo movement, in 10^3 tons, in the port between the years of 1990 and 2012 is represented in the graph shown in Figure 13. The movement of cargo, by type, in the year of 2012 is shown in Figure 14.

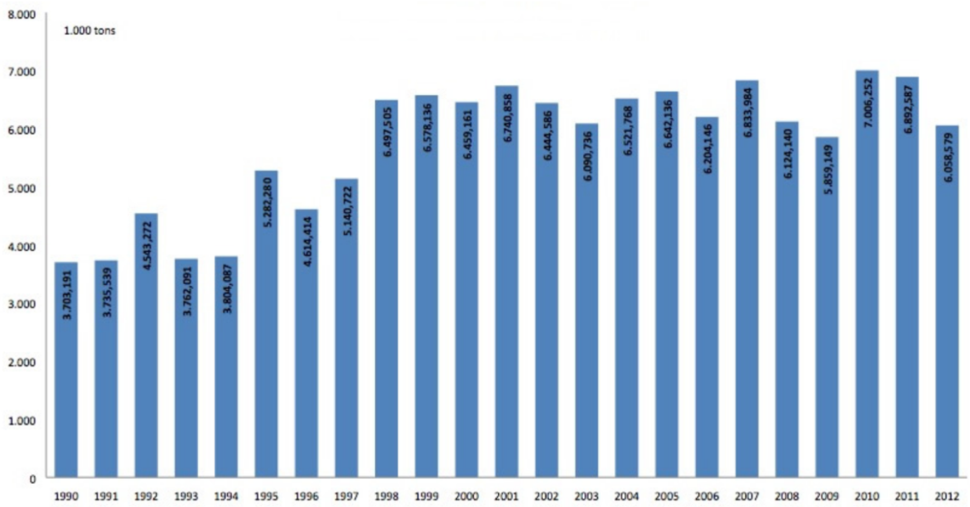


Figure 13: Cargo movement in the port of Setúbal between the years of 1990 and 2012 – Administração dos Portos de Setúbal e Sesimbra

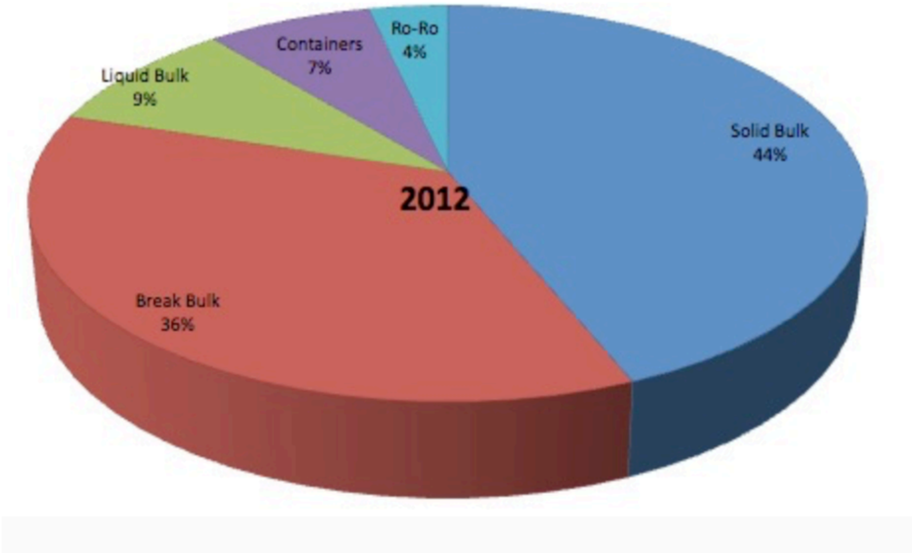


Figure 14: Cargo movement by type in the port of Setúbal in the year of 2012 - Administração dos Portos de Setúbal e Sesimbra

3.1.4.1 Sadoport Terminal

This terminal is operated by Sadoport and is used for handling break bulk and general cargo, Ro-Ro (heavy) and containers. It has the following characteristics:

- A wharf front of 725m long, with depths of -15m (CD) (4 mooring berths);
- Drafts of -12m (CD);
- Covered storage areas of 1.619 square meters and 200.778 square meters of open air storage areas;
- A gantry crane of 45 tons and one of 40 tons (post-panamax).

All information was provided by the Setúbal and Sesimbra ports administration and Figure 15 shows the multipurpose terminal operated by Sadoport.

Figure 15: Multipurpose terminal operated by Sadoport in the port of Setúbal

3.2 Road and rail transport in Portugal

Over 235 million tons of goods were transported in Portugal in 2013, in which road transport represented 62,67% of this total, maritime transport 33,29%, rail transport 3,95% and air transport only 0,09% (Martins, 2015).

At the end of 2013, Portugal had 14310 Km of roads, 3065 Km of which were highways and 83% of all goods transported by road had as a final destination Spain, France, Germany, Italy and The Netherlands (Martins, 2015). The quantities of cargo transported by road in Portugal from 2015 to 2018 are represented in Table 5 (Anuário Estatístico da Mobilidade e dos Transportes, 2018).

Table 5: Quantity of cargo transported by road – Estatísticas dos Transportes e Comunicações (Source: INE (2015-2018))

Cargo Transported	2015	2016	2017	2018
1000 TON	162956	148532	157590	156658

As for its rail transport, there were 3619,3 Km of railways in Portugal, 2544,4 Km of which were being used in 2013 (Martins, 2015). The quantities of cargo transported by rail in Portugal from 2015 to 2018 are represented in Table 6 (Anuário Estatístico da Mobilidade e dos Transportes, 2018). It is also important to mention that rail transport is the most operational efficient, economic, sustainable and less bureaucrat option in order to improve maritime flow through inland connections. Also, railways have the potential to optimize the whole transportation process by adopting new information and communication technologies, which impact directly container terminals operations (Tonga, 2018).

Table 6: Quantity of cargo transported by rail – Estatísticas dos Transportes e Comunicações (INE)

Cargo Transported	2015	2016	2017	2018
1000 TON	11094	10378	10632	10634

Figures 16 and 17 represent the highways, as most of the cargo transported by road is transported in highways, and railways of Portugal, respectively. The motorway network has been fully included in the model used in the Intermodal Analyst software, which is described further in this thesis. The rail network has been partially included in the same model, because only those railway lines known to regularly receive freight trains were included.

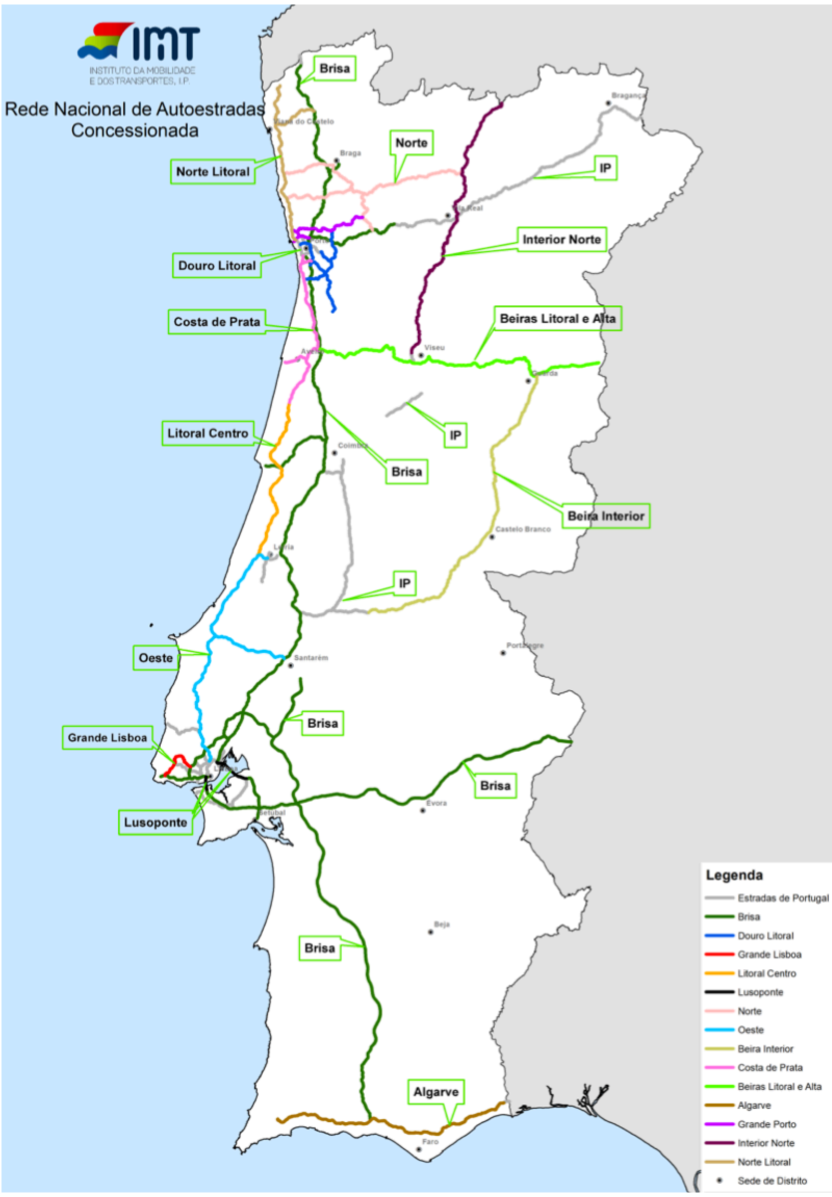


Figure 16: Highways of Portugal – Infraestruturas de Portugal

Figure 17: Railways of Portugal – Infraestruturas de Portugal

3.3 Multimodal terminals

A multimodal terminal is usually directly connected to seaport(s) with high capacity transport mean(s), where customers can leave/pick up their standardized units as if directly to a seaport. Also known as dry ports, these multimodal terminals frequently use railways to move cargo. Figure 18 shows some of the freight rail terminals located in the transportation network used in this thesis, and also indicates which transportation node corresponds to each terminal. These nodes are part of the database provided by the Intermodal Analyst software, which is described in the next section of this thesis.

 Terminal ferroviário de Leixões – Node 629	 Terminal da SPC Valongo – Node 630	 Terminal de Tadim (Braga) – Node 651
 Plataforma Logística Cacia – Node 406	 Terminal de Alfarelos – Node 635	 Terminal da Guarda – Node 642
 Terminal de Mangualde – Node 641	 Terminal TVT – Node 28 (same as MSC)	 Terminal MSC Entroncamento – Node 28
 Terminal Bobadela – Node 16	 Terminal Vale da Rosa – Node 122	 Terminal de Elvas – Node 242
 Terminal de Leiria – Node 780	 Terminal San Lázaro (Mérida) – Node 330	--

Figure 18: Freight rail terminals in Portugal and Extremadura

4. GEOGRAPHIC INFORMATION SYSTEMS APPLIED TO HINTERLAND ANALYSIS

As mentioned in previous sections, the purpose of this thesis is to use a Geographic Information Tool in order to represent graphically the results of numerical models related to the transportation of containerized cargo from locations across Portugal and in some regions of Spain, to Portuguese container terminals. The GIS software used in this thesis is QGIS and the inputs used were provided by the Intermodal Analyst software.

4.1 Geographic Region Model

Generally, cargos are considered to be concentrated in the main cities and towns corresponding to capitals of Portuguese municipalities or of Spanish comarcas (covering the cross-border provinces of Badajoz, Caceres, Salamanca and Zamora). The equivalent to Portuguese municipalities in Spain is the *ayuntamiento* but these were found to be too small in comparison with Portuguese municipalities. Therefore, a larger administrative unit, the comarca, was chosen to be used in this model.

The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the European Union and the United Kingdom for the purpose of the collection, development and harmonization of European regional statistics. This division is also important to do a socio-economic analysis of the regions, where NUTS-1 are major socio-economic regions, NUTS-2 are basic regions for the application of regional policies and NUTS-3 are small regions for specific diagnosis (Eurostat).

Currently, Portugal has 308 municipalities which are divided in 25 NUTS-3 regions, 7 NUTS-2 regions and 3 NUTS-1 regions. The NUTS-2 Portuguese North and Center regions are shown in Figure 19, while Figure 20 shows the NUTS-2 Lisbon Metropolitan area, NUTS-2 regions of Alentejo and Algarve. As of Spain, the whole country has 7 NUTS-1 regions, 19 NUTS-2 regions and 59 NUTS-3 regions, with a total of 8124 municipalities. Figure 21 shows the NUTS-2 Spanish regions of Estremadura and Castilla y Leon.

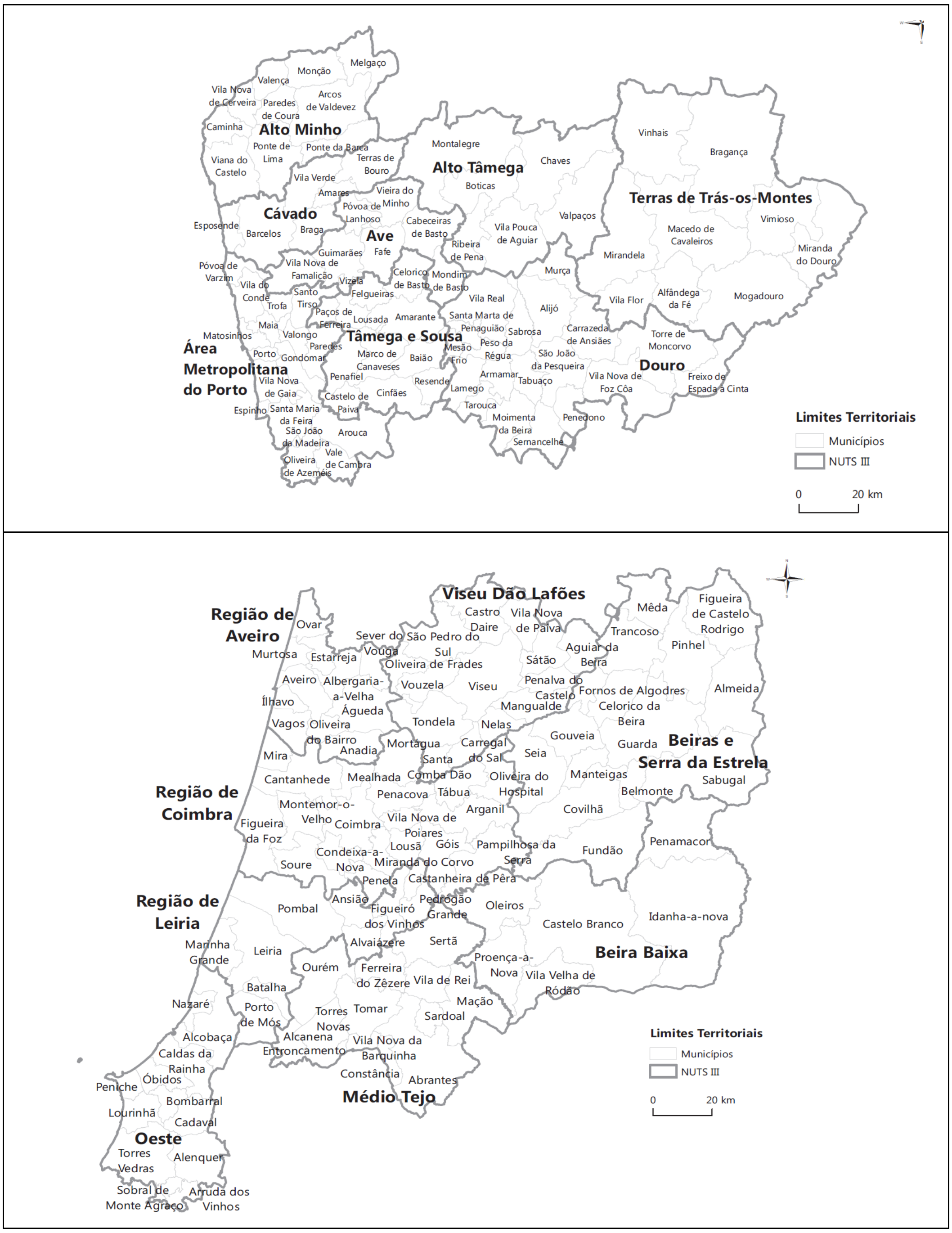


Figure 19: Municipalities in NUTS 2 – North and Center

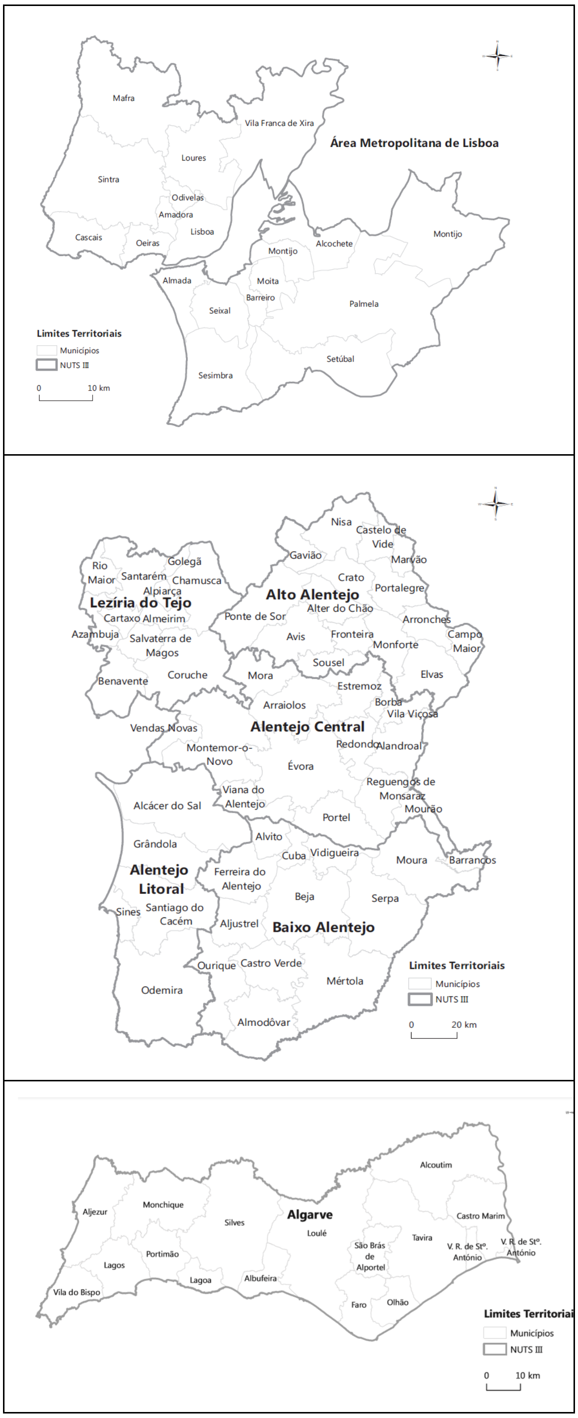


Figure 20: Municipalities in NUTS 2 – Lisbon Metropolitan Area, Alentejo and Algarve

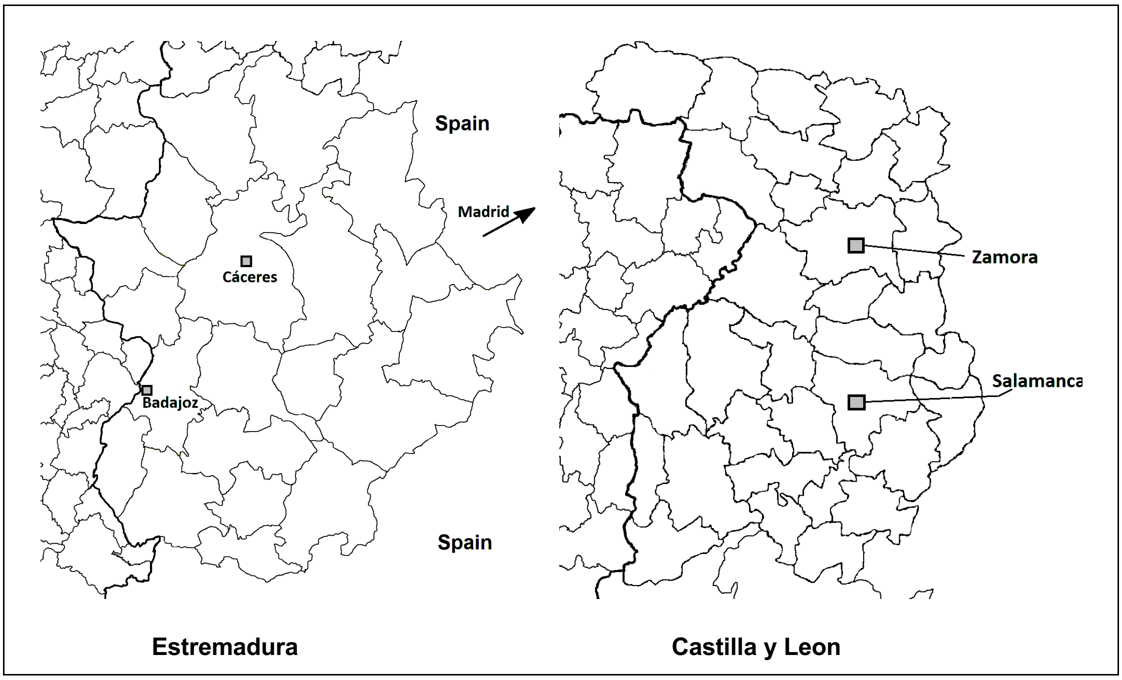


Figure 21: Comarcas in Spanish provinces of Badajoz, Caceres, Salamanca and Zamora

4.2 Intermodal Analyst software

The Intermodal Analyst is a Fortran coded software developed by Tiago Santos in the research unit CENTEC of IST, University of Lisbon. The objective of the software is to calculate the cost and time of transport between an origin and a destination. The origin is considered to be the point in space where the cargo is loaded on a mode of transportation and the destination is the point in space where the cargo is unloaded. The voyage undertaken by the cargo may be unimodal or intermodal and the typical cargo considered is equivalent to a Forty Feet Unit (FEU). The modes of transport available in the transport network are the road, rail, maritime (container ship or Ro-Ro ship) and inland waterway (barge) (Intermodal Analyst User Manual, 2020).

The software is controlled with a log file, which receives the input data files, in txt format, that contains the network database, cost database, path database and also the cargo database. This information allows the software to calculate the cost/time results, cargo distribution and the paths as links, which are the output data files given by the software, also in txt format. Figure 22 represents the Intermodal Analyst flowchart (Intermodal Analyst User Manual, 2020).

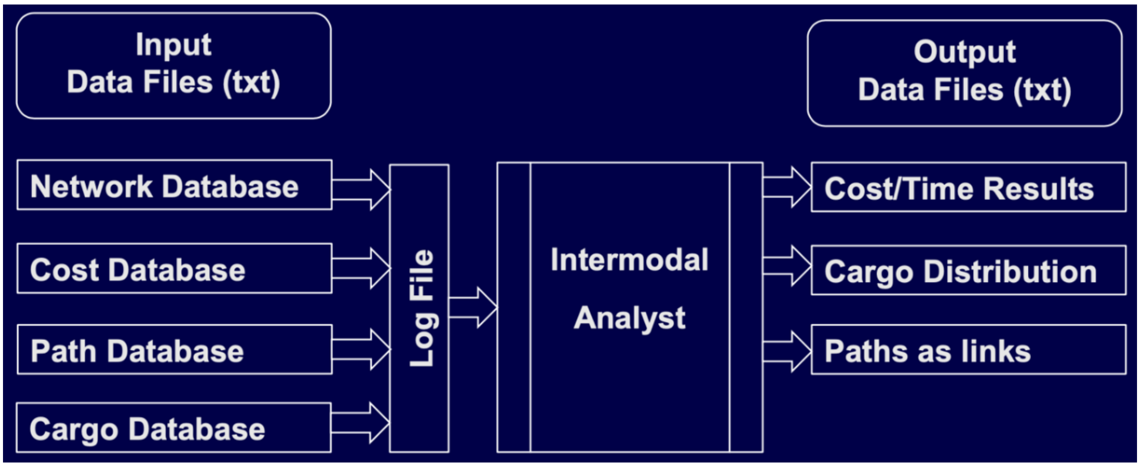


Figure 22: Intermodal Analyst software flowchart

In the transport network defined in the database, there are transportation nodes and links. Transportation nodes may represent road junctions, rail junctions, inland waterway junctions, seaport terminals, intermodal terminals or cities. Also, sea routes may have nodes inserted at suitable points and border between countries are also supposed to be represented by nodes. After the node definition, the links are defined, which may be roads, motorways, urban (streets), rails, inland waterways, container ship sea routes or Ro-Ro ship sea routes (Intermodal Analyst User Manual, 2020).

Assume a transportation network with N nodes L and links, with n and l representing individual nodes and links. Links are characterized by attributes such as the length of each link, d_l, and the average speed in the link, s_l. As for the nodes, they are characterized by the time spent in each node, which is zero unless for intermodal and seaport terminals, where this attribute is t_n and t_s, respectively. The time spent in terminals, t_n and t_s, are composed of the waiting time at the gate, time required to handle the containers and the dwell time in the storage yard (Santos et al., 2019).

Taking in consideration this, the total accumulated transit time through an individual path is given by equation 1, where δ_{rl} is a binary variable to consider whether the link is used in route r or not and δ_{rn} is a binary variable to consider whether the node is used in route r or not (Santos et al., 2019).

$$T_r = \sum_{l=1}^{L}(\delta_{rl}.\, d_l.\, s_l) + \sum_{n=1}^{N}(\delta_{rn}.\, d_n.\, s_n) + t_s \qquad (1)$$

The cost model used in this software comprises separate costs associated to road and rail on a per TEU.km basis (c_{l-road} for specific transport cost by road and c_{l-rail} for specific transport cost by rail), which are user specified and correspond to average costs as perceived by the user of the transportation network. Also, costs are specified in certain nodes of the network where container handling occurs, such as intermodal terminals and seaport terminals. In the first case, the cost of unloading and loading the container from the truck or train to/from the container yard is C_{nu} and C_{nl}. As for seaport terminals, these same costs are defined by C_{su} and C_{sl} (Santos et al., 2019).

Finally, storage of containers in intermodal and seaport terminals may also have additional costs, depending on the number of free days, t_f, allowed by the terminal operator. The number of free days and the daily storage cost, c_{nSt} and c_{sSt}, are used to calculate the storage costs in intermodal terminal n and in seaport terminal s, as shown in equations 2 and 3 (Santos et al., 2019).

$$C_{nSt} = \left(t_n - t_f\right). c_{nSt} \quad (2)$$

$$C_{sSt} = \left(t_s - t_f\right). c_{sSt} \quad (3)$$

Considering the definitions presented so far, the total cost in a given path r may be calculated as follows in equation 4:

$$C_r = [\sum_{l=1}^{L}(\delta_{rl-road}. d_{l-road})]. c_{l-road} + [\sum_{l=1}^{L}(\delta_{rl-rail}. d_{l-rail})]. c_{l-rail} + \sum_{n=1}^{N}[\delta_{rn}(C_{nu} + C_{nl} + C_{nSt})] + C_{su} + C_{sl} + C_{sSt} \quad (4)$$

The generalized cost in path r, C_{gr}, is then calculated as a function of total cost C_r, transit time T_r and the value of time (VOT) for the cargo in the container:

$$C_{gr} = C_r + VOT. T_r \quad (5)$$

After calculating the generalized cost associated with each path r from a load centre, c, to a seaport, s, it is possible do determine which path has the lowest generalized cost, as shown in equation 6, where Rcs is the set of paths between the load centre and seaport analyzed.

$$C_{g\,min_{cs}} = min\left(C_{gr}\right)_{r \in Rcs} \quad (6)$$

Similarly, the seaport s with the lowest generalized cost for each load centre c is determined in equation 7, where S is the set of all seaport terminals available. This result is important because it shows which load centers are part of the main hinterland of the terminal.

$$C_{g\,min_c} = min\left(C_{gr_{min_{cs}}}\right)_{s\in S} \quad (7)$$

At last, the level of competition between seaport terminals is measured using the hinterland contestability index, CI_c.This index is defined as the number of seaport terminals presenting a generalized cost not higher than 25% of the minimum generalized cost among the studied terminals. In other words, CI_c is the cardinal of the set of terminals whose generalized costs are within the 25% range described in equation 8:

$$CI_c = card\{s: C_{g\,min_{cs}} \in [C_{g\,min_c}; 1.25 \times C_{g\,min_c}]\} \quad (8)$$

4.3 QGIS software

The Geographic Information System tool used in this thesis is QGIS, which is a free software that supports numerous vector, raster and database formats and functionalities.

Before starting to add any information to the project, it is necessary to have a proper map to be able to work using the software. In order to do that, an OpenStreetMap layer was added to the project, which can be seen in Figure 23. It is also important to mention that the coordinate reference system used was the WGS 84/ Pseudo-Mercator, which corresponds to the authority ID EPSG: 3857 in the QGIS project properties.

Figure 23: OpenStreetMap layer

4.3.1 Roads

Using shapefiles, two vector layers were added to the map in order to represent the road system in Portugal and Spain, as can be seen in Figure 24.

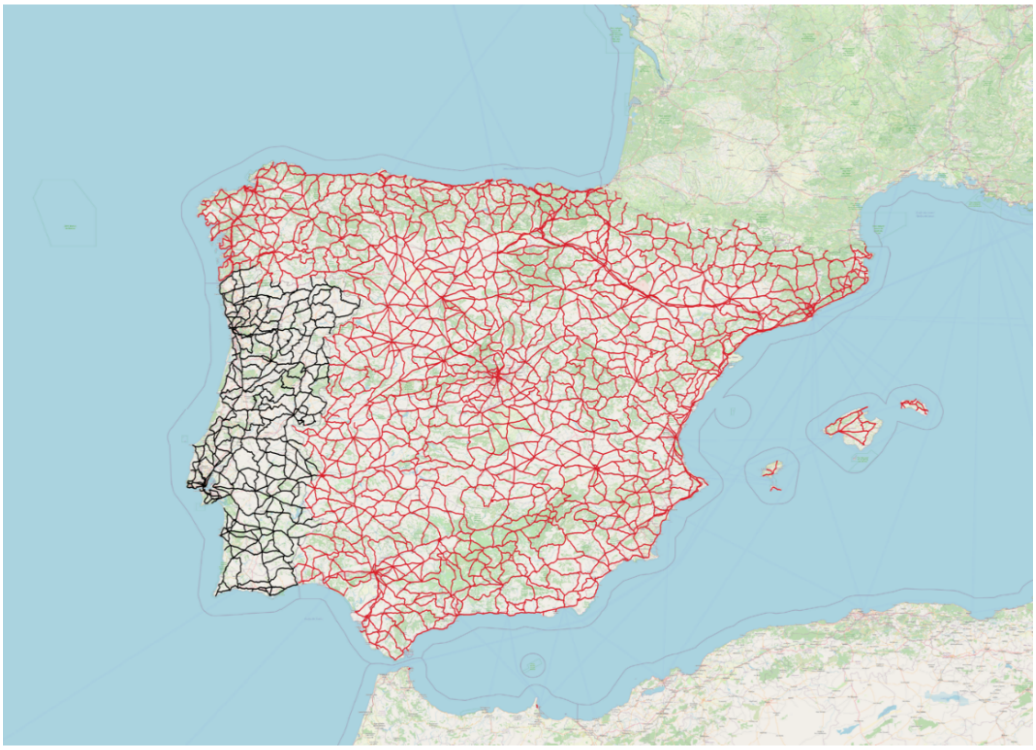


Figure 24: Roads in Portugal (black) and Spain (red)

4.3.2. Railways

Similar to the previous section, another two vector layers were added, also using shapefiles, this time to represent the railways in Portugal in Spain, as shown in Figure 25.

Figure 25: Railways in Portugal (purple) and Spain (blue)

4.3.3. Transportation nodes

All transportation nodes used in this thesis were provided by the Intermodal Analyst software in *txt* format. This file contains several information about the nodes, such as cargo handling costs, cargo handling time, the identification of the node, its name and latitude and longitude coordinates.

In order to represent the nodes in the map as points, it is necessary first to convert the file to *csv* format using excel, and then add it in QGIS as a delimited text layer. Additionally, it must be checked if the coordinate reference system in this new layer is the same as the one used in the project, if not, it must be changed. Figure 26 shows all transportation nodes in Portugal and the ones in the provinces of Badajoz, Caceres, Salamanca and Zamora, in Spain.

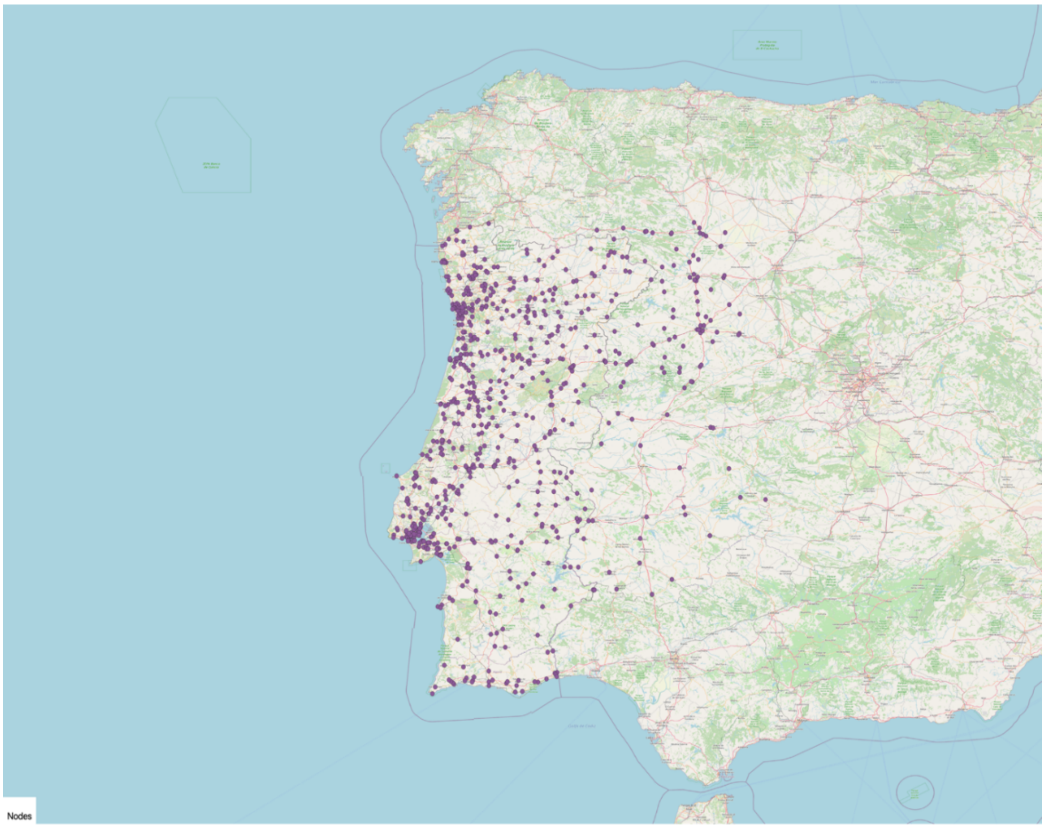


Figure 26: Transportation nodes in Portugal and in the provinces of Badajoz, Caceres, Salamanca and Zamora, in Spain

4.3.4. Data upload

The Intermodal Analyst provides all data to be uploaded to the maps, also in txt format, which again had to be converted into a csv file in excel in order to be used in QGIS. As the objective in this thesis is to do an analysis among Portuguese and Spanish regions, it was necessary to add layers with the administrative areas of these countries to the project, using shapefiles. These shapefiles containing the cities of Portugal and the counties of the provinces of Badajoz, Caceres, Salamanca and Zamora, in Spain, were downloaded from DIVA-GIS website, which provides free spatial data for the whole world, that can be used in all GIS related tools, and also from the website of the ministry of agriculture, fisheries and food from the government of Spain. After adding these layers, the Spanish counties outside the provinces of interest were deleted from the map, and both layers were merged using the merge vector layers option, under data management tools. Figure 27 shows the regions analyzed in this thesis.

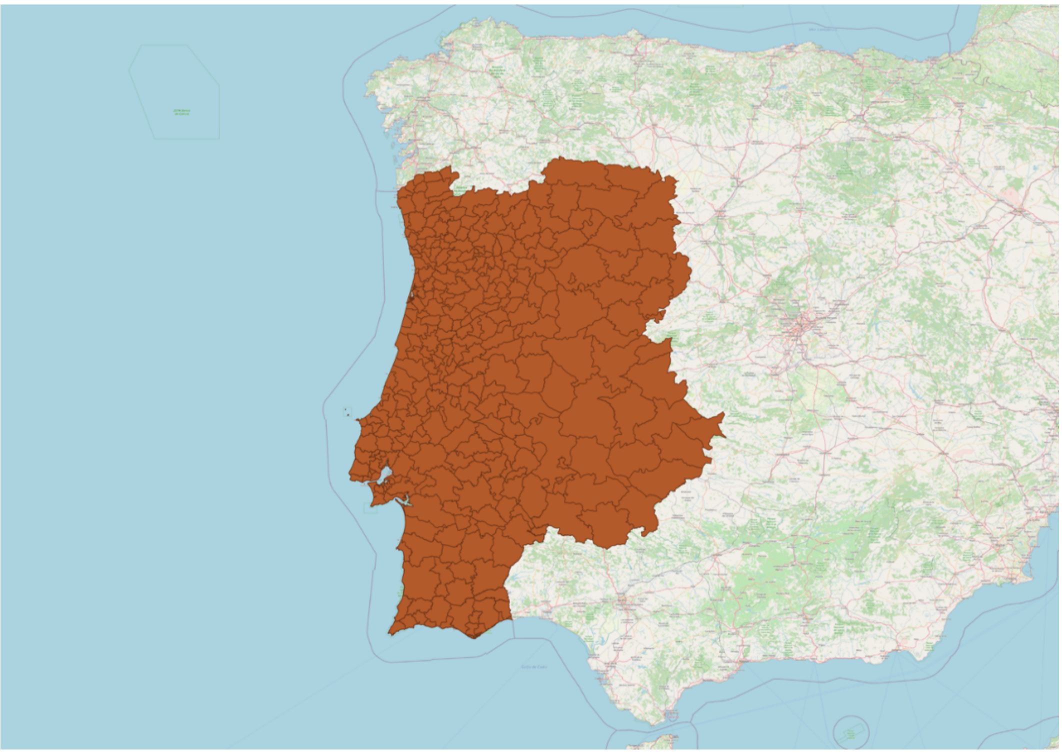


Figure 27: Portuguese cities and Spanish counties from the provinces of Badajoz, Caceres, Salamanca and Zamora

Once these layers were added to the map, their attribute table had to be checked in order to verify how the cities and counties were presented. As their names were used to identify each segment, and the data provided by Intermodal Analyst uses the nodes number, it was necessary to list all nodes and rename them using the exact identification shown in the attribute table of the layers.

Using this new identification, all data used must also be converted into a *csv* file before being able to add them to the project. After adding the *csv* files data to QGIS, they were joined to the administrative areas layer using the join command inside the layer properties. This new data, however, is recognized as a string by the software, and this way it is not possible to represent the data graphically. The conversion of the new data from string to real number is possible by using the toggle editing mode of the attribute table and writing a simple expression in the field calculator, using the *to_real* function.

5. APPLICATION TO HINTERLAND ANALYSIS IN PORTUGAL

The situation regarding containerized cargo in Portuguese ports is to be analyzed regarding the relative competitiveness of terminals. Container terminals to be considered are Leixões (TCL), Lisbon (Liscont and Sotagus), Setúbal (Sadoport) and Sines (Terminal XXI).

In the first phase, only road transportation of containers will be considered from each municipality or comarca to every port terminal. In a second phase, rail transport of containers will be added as an option to certain port terminals: Sines Terminal XXI. Trains currently go to Sines from intermodal terminals in Leixões, São Martinho do Campo (Valongo), Entroncamento and Vale do Sado (Praias do Sado).

For the first phase, with no container rail transportation in operation, the transportation time, transportation cost and generalized transportation cost to a container terminal from all municipalities and comarcas will be analyzed. After this analysis, the minimum transportation cost, minimum transportation time and minimum generalized transportation cost from each municipality and comarca will be determined, making it possible to define the hinterlands of the analyzed terminals regarding these parameters. At last, it will also be determined the contestability index between terminals, which is the number of terminals for each municipality and comarca that have a generalized transportation cost within 25% of the most competitive terminal.

For the second phase, rail transportation will be included and the same analysis made in phase one will be done, but now only for Terminal XXI in the port of Sines. Also, it will be determined for which municipalities and comarcas it is better to use rail transportation based on the minimum transportation cost, minimum transportation time and minimum generalized transportation cost and in which cases the use of rail transport results in any savings when comparing to road only transportation.

Finally, the results from the first and second phases of analysis will be compared, in order to determine if having the option to transport cargo to the port of Sines using a combination of road and rail modes impacts the main inland hinterlands of the terminals.

5.1. Parameters considered for each terminal

The seaport terminals analyzed are defined by Intermodal Analyst using certain parameters, such as cargo unloading cost, cargo loading cost, average time in terminal, time of free storage, cost of storage and time of port call. The values considered for each terminal are described in Table 7 and were taken from the terminals Regulations on Tariffs.

Table 7: Parameters considered for each terminal

	Alcantara	Leixões	Santa Apolonia	Setubal	Sines
Cargo Unloading Cost (€)	30	0	23,2	29,5	27
Cargo Loading Cost (€)	118	142,2	110,4	152	115,5
Average Time in Terminal (h)	96	24	24	96	96
Time of Free Storage (h)	72	120	120	48	72
Cost of Storage (€)	1,09	1,79	1,45	0,5	2,68
Time of Port Call (h)	10	6	6	10	10

5.2. Road only transportation

First of all, it is important to mention that as regards the transportation cost, transportation time and generalized transportation cost from each municipality and comarca to the terminals, only the maps regarding the container terminal in Leixões will be presented in this section. The maps for the other analyzed terminals are available in the Annex C of this thesis. For the minimum transportation cost, minimum transportation time, minimum generalized transportation cost, the hinterlands of the terminals regarding these last parameters and also for the competition level, all maps will be presented in this section.

Before presenting the maps, the results given by Intermodal Analyst from node 46 (Almada) to the analyzed terminals will be exemplified in Table 8.

Table 8: Results given by Intermodal Analyst from node 46 (Almada) to the analyzed terminals

Terminal	Transportation Cost	Transportation Time	Generalized Transportation Cost
	€	hours	€
Alcantara Terminal	64,00	1,06	540,47
Santa Apolonia Terminal	176,32	1,08	644,61
Setubal	178,20	0,76	692,26
Sines	267,20	2,25	752,41
Leixões	666,08	5,27	1176,66

5.2.1. Transportation cost

Figure 28 shows the transportation cost (in euros) from the various municipalities and comarcas to the container terminal in the port of Leixões. As a first conclusion, it may be noted that, in general, the larger the distance from the municipality to the terminal, the higher the transportation cost, which ranges from 40 € to 1200 €. As might be expected, the smallest values occur for municipalities around Leixões (Oporto metropolitan region), while regions of southeast Extremadura and southern Portugal exhibit the highest values. However, a closer look at this figure shows details such as the influence of the existing road network in transportation cost as it enables some reduction in distances. This is particularly clear in northern Portugal, where the region all along the motorway from Aveiro to the Spanish border (see Figure 25) shows lower transportation costs.

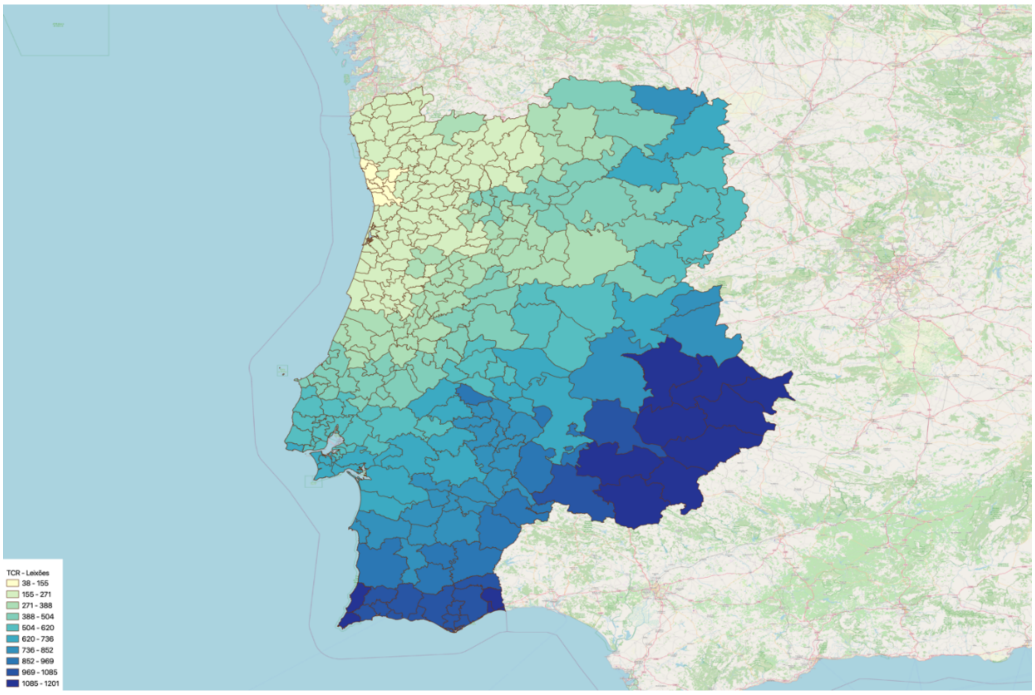


Figure 28: Transportation cost (road only) – Leixões

5.2.2. Transportation time

Figure 29 shows the transportation time (in hours), also indicated in the literature as transit time, from the various municipalities and comarcas to the container terminal in the port of Leixões. This time ranges from less than 1 hour (Oporto metropolitan region and Minho) to almost 10 hours (southeast Extremadura). The transportation time includes the time required for pauses of the truck drivers, if needed, as per Portuguese and European law. Again, the influence of the road network is evident in the figure as the motorways allow higher average truck speeds. The average speed in the road and rail networks considered in Intermodal Analyst is shown in Table 9.

Table 9: Average speed considered in the road and rail networks

	Average Speed (km/h)
Motorways	80
Roads	60
Urban	40
Bridges (depending on the bridge)	40-60
Rail	37

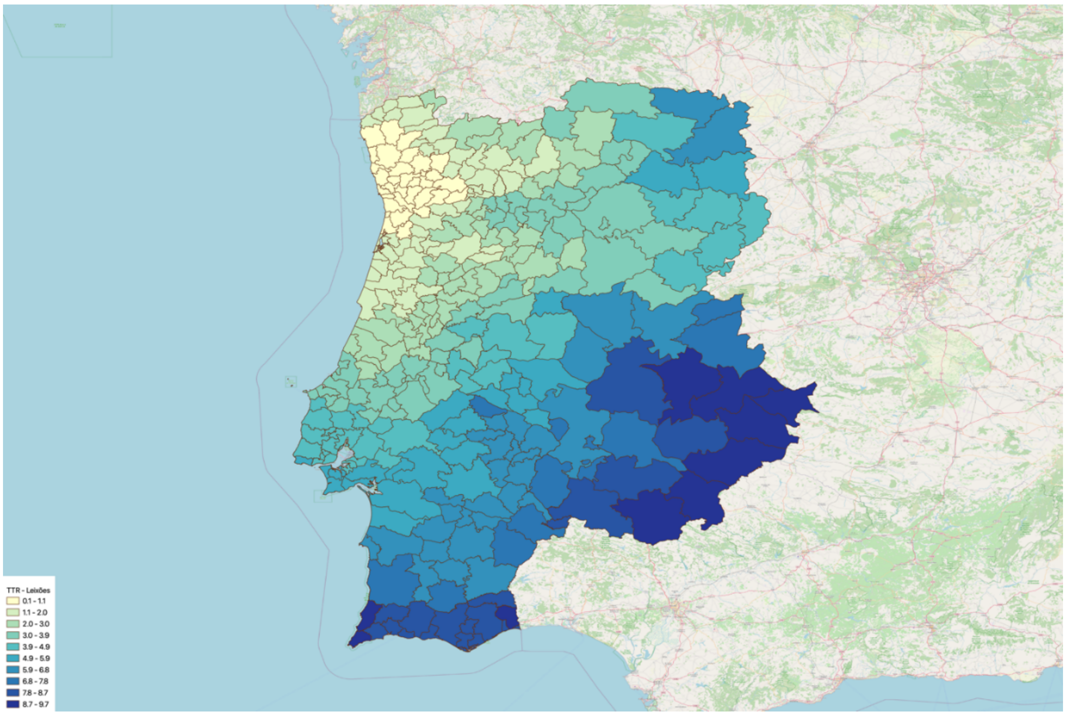


Figure 29: Transportation time (road only) – Leixões

5.2.3. Generalized transportation cost

Figure 30 shows the generalized transportation cost (in euros), GTC, also indicated in the literature as transit time, from the various municipalities and comarcas to the container terminal in the port of Leixões. In the calculation of GTC a value of time for cargo of 6.82 €/hour per cargo unit has been considered. The time used in the calculation of GTC is not only the transportation time of Figure 27, but also the average time spent in the container terminal by each container (approximately equivalent to the dwell time) up to the point when the container is loaded onboard the ship. In this way, the GTC is sensitive to the efficiency of the container terminal in the sense that if the terminal operator manages to reduce the dwell time, the GTC will be decreased.

Obviously, this same Figure could have been created based on a GTC calculated with the transportation time, but it would not show the effect of terminal efficiency.

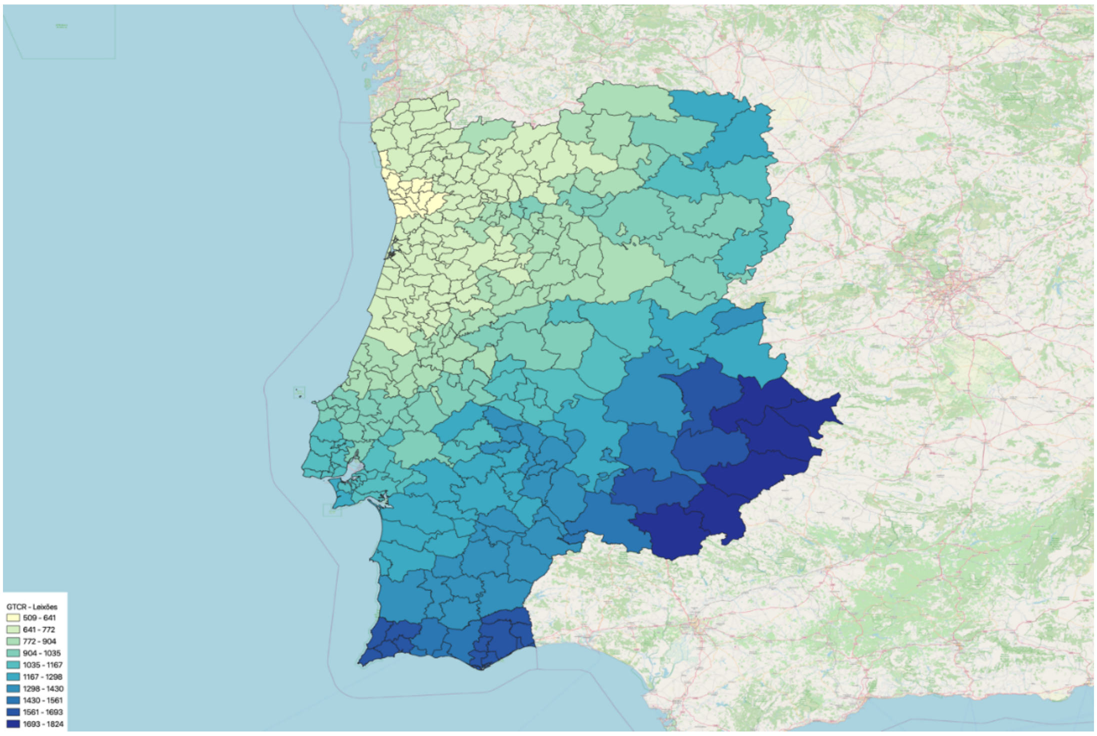


Figure 30: Generalized transportation cost (road only) - Leixões

5.2.4. Minimum transportation cost

Figure 31 shows the minimum transportation cost (in euros) for each Portuguese municipality and Spanish comarca, considering all analyzed terminals. It is possible to see that the lowest transportation costs occur in regions close to the ports of Sines, Setúbal, Lisboa and Leixões because of the shorter transportation distances. The highest costs are observed in the Spanish comarcas located far from the Portuguese border, as the distance impacts directly the transportation cost. Once again, it is clearly visible the influence of the three motorways leading from Portugal to Spain (from North to South, through Bragança, Vilar Formoso and Caia). Along the Portuguese coast, only some parts of the central part of the country and Algarve (south coast) are comparatively not so well served in terms of cheap access to container terminals.

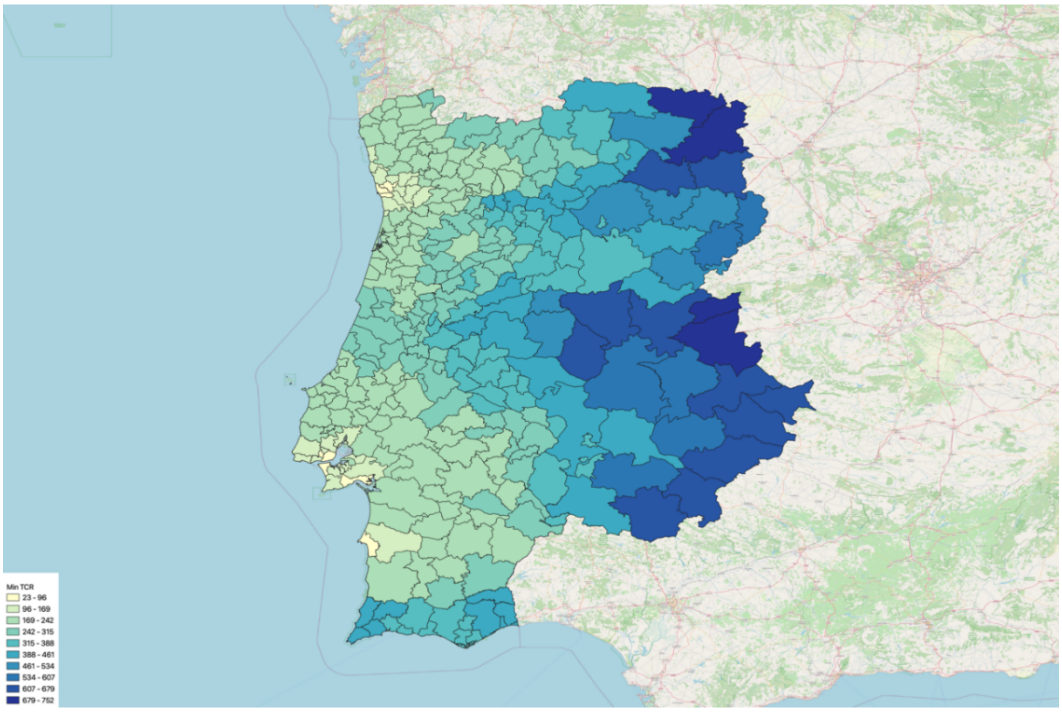


Figure 31: Minimum transportation cost (road only)

5.2.5. Minimum transportation time

Figure 32 shows the minimum transportation time (in hours) for each Portuguese municipality and Spanish comarca, considering all analyzed terminals. Similar to what is observed in Figure 29, the lowest transportation times are seen in regions close to the ports of Sines, Setúbal, Lisboa and Leixões because of the shorter transportation distances and the highest times occur in the Spanish comarcas located far from the Portuguese border, as the distance impacts directly also the transportation time.

Also, all municipalities in Portugal are within about 4 hours reach of one container terminal. The highest transportation times occur for municipalities in Beira Baixa, Beira Alta and Algarve, in portions of such regions further away from motorways. Evidently, the municipalities surround the container terminals show the lowest times. It is interesting to note again that an extensive area between Leiria and Coimbra, although located in the coastal region, still shows transportation times of approximately 2 hours, as the containers need to be carried to either Lisbon or Leixões (nearest ports).

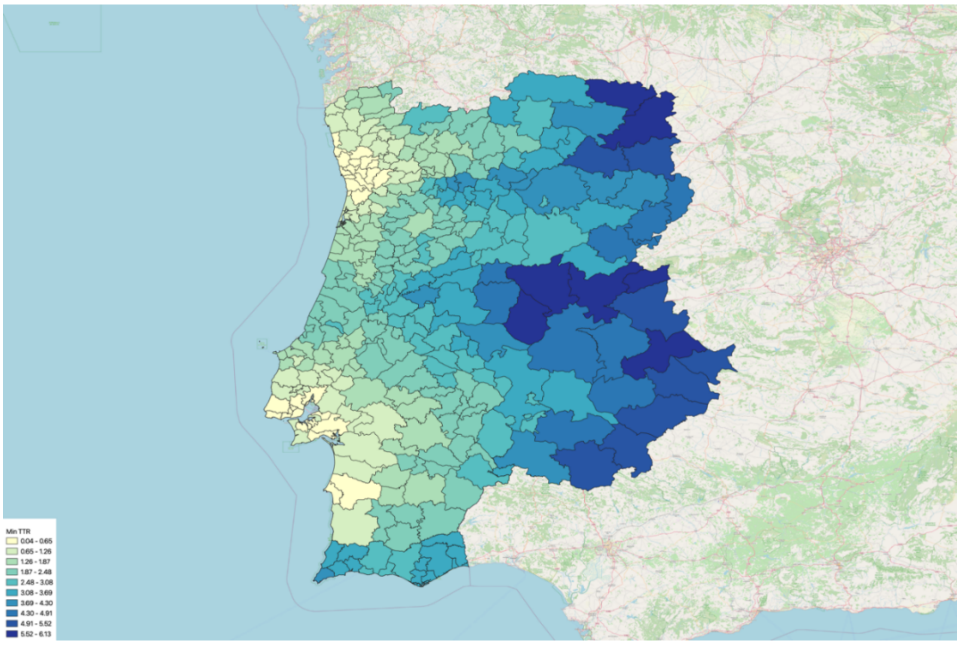


Figure 32: Minimum transportation time (road only)

5.2.6. Minimum generalized transportation cost

Figure 33 shows the minimum GTC (in euros) for each Portuguese municipality and Spanish comarca, considering all analyzed terminals. The results are also similar to the ones observed for the minimum transportation cost and minimum transportation time, as the GTC is also sensitive to the distance in which the cargo has to be transported. The entire Metropolitan areas of Porto and Lisbon (and along the coast southwards till sines) are well served in terms of having low GTCs.

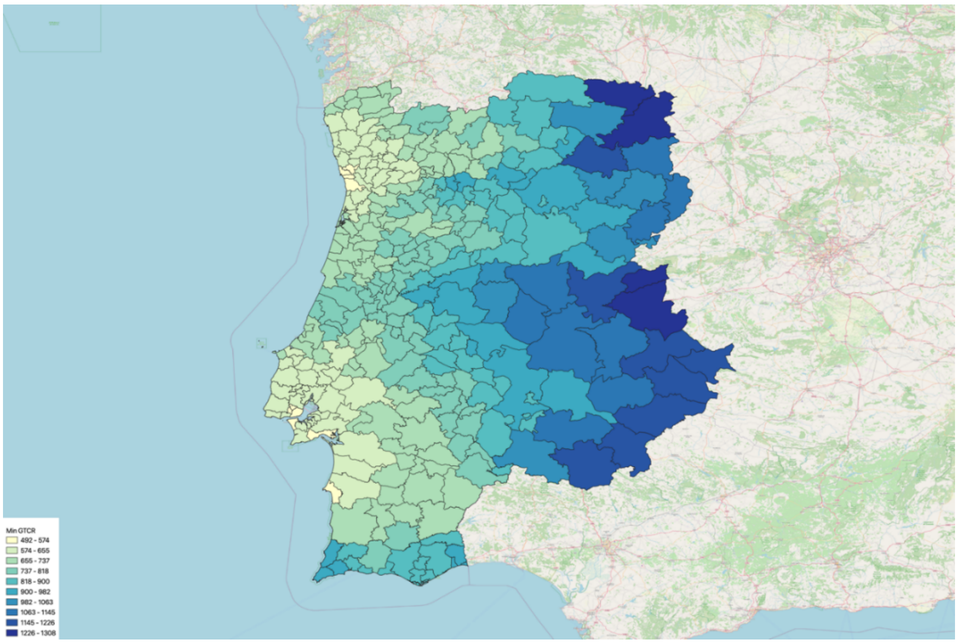


Figure 33: Minimum generalized transportation cost (road only)

5.2.7. Container terminal hinterland (as per transportation cost)

Figure 34 shows, for each municipality and comarca, the container terminal for which the transportation cost is lower. When the analyzed factor is the transportation cost, it is possible to see that the Port of Sines has a clear advantage in the municipalities in the region of Algarve, Alentejo Litoral, Baixo Alentejo, and for most municipalities in the center and north of the country, as well as comarcas in the provinces of Salamanca, Zamora and some comarcas in the province of Caceres, the port of choice would be Leixões if the decisive factor is the transportation cost only.

The port of Setúbal has lower transportation costs for Portuguese municipalities in located in Alentejo Central and some in Alto Alentejo and parts of the Lisbon metropolitan area, and also in comarcas in the province of Badajoz and some in the province of Caceres, in Spain.

As for the terminals of Santa Apolónia and Alcântara, both located in the Lisbon metropolitan area, the first one has transportation costs advantages in most municipalities in Leiria, Médio Tejo, Leziria do Tejo, Oeste, and some in Alto Alentejo and in the Lisbon metropolitan area. Finally, Alcântara terminal is the one with the smallest hinterland in this scenario, being the best choice only for some municipalities in the Lisbon metropolitan area.

Some “island” of hinterland may be seen in the close vicinity of Lisbon. This is because the terminals of Alcântara and Santa Apolónia have very similar results and any small variation in a parameter may cause these variations in attribution of municipalities to each terminal’s hinterland.

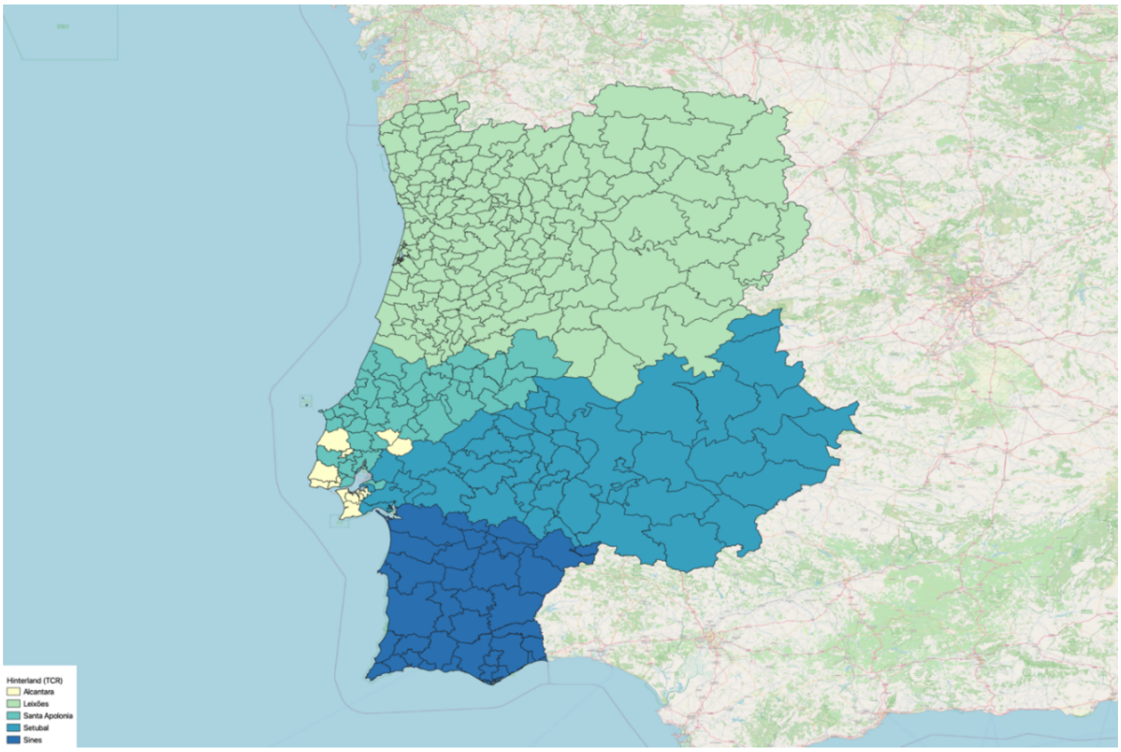


Figure 34: Hinterland (transportation cost – road only)

5.2.8. Container terminal hinterland (as per transportation time)

Figure 35 shows, for each municipality and comarca, the container terminal for which the transportation time is lower. The hinterlands of the analyzed terminals regarding the transportation time are almost the same as the hinterlands presented in the previous section, in which the transportation cost was the decisive factor.

When taking the transportation time into consideration, the terminal of Alcântara has a hinterland composed of only 5 Portuguese municipalities: Sintra, Cascais, Oeiras, Amadora and Barreiro in the Lisbon metropolitan area, and also the municipality of Batalha. Even though Batalha is located among other municipalities from the Santa Apolónia terminal hinterland, its transportation time to the terminal of Alcântara is 2,53 hours and to the terminal of Santa Apolónia is 2,54 hours. This result is understandable, as almost all municipalities in this range have similar transportation times to both terminals. This implies that the numerical results for the Alcântara and Santa Apolónia terminals are very close and any small variation may cause an “island” of hinterland such as this in Batalha to emerge. The conclusion is that as both terminals are in the same port, and are located not so distant from each other, their hinterlands are in fact very similar.

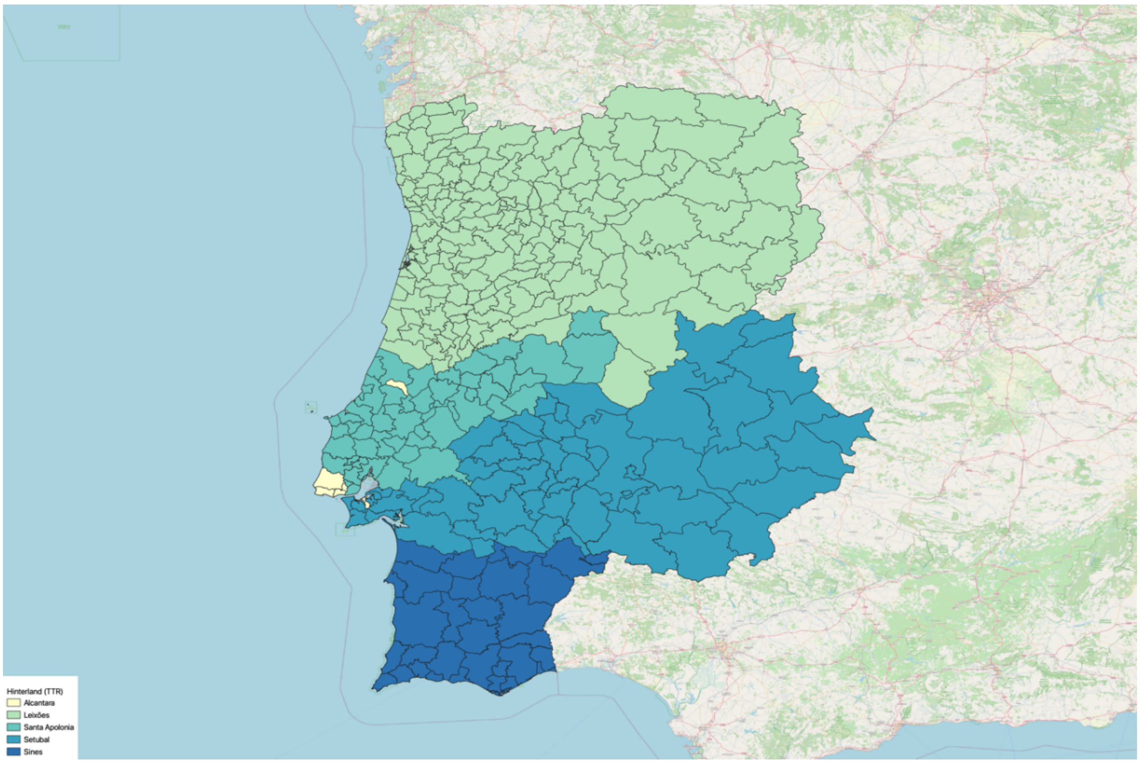


Figure 35: Hinterland (transportation time – road only)

5.2.9. Container terminal hinterland (as per generalized transportation cost)

Figure 36 shows, for each municipality and comarca, the container terminal for which the generalized transportation cost is lower. As the GTC is calculated based on the transportation cost plus the dwell time in terminal, any inefficiency in terminal operation would reduce the hinterland of the terminal.

It is possible to observe that the hinterland of the Port of Sines and the hinterland of the Port of Leixões did not present any significant changes when compared to the hinterlands considering the transportation cost and transportation time. As for the Port of Setúbal, it lost part of its hinterland in Alentejo Central to the Santa Apolónia terminal probably for being less efficient and having a longer dwell time, and Alcântara terminal continued to have a hinterland composed mainly of municipalities located in the Lisbon metropolitan area. In this scenario, in which the generalized transportation cost is the decisive criteria, the Port of Leixões has the largest hinterland, when compared to the other analyzed terminals. The Port of Sines, Setúbal and the Santa Apolónia terminal present hinterlands with approximately the same area, and the terminal of Alcântara has a hinterland composed of only 7 municipalities in the Lisbon metropolitan area.

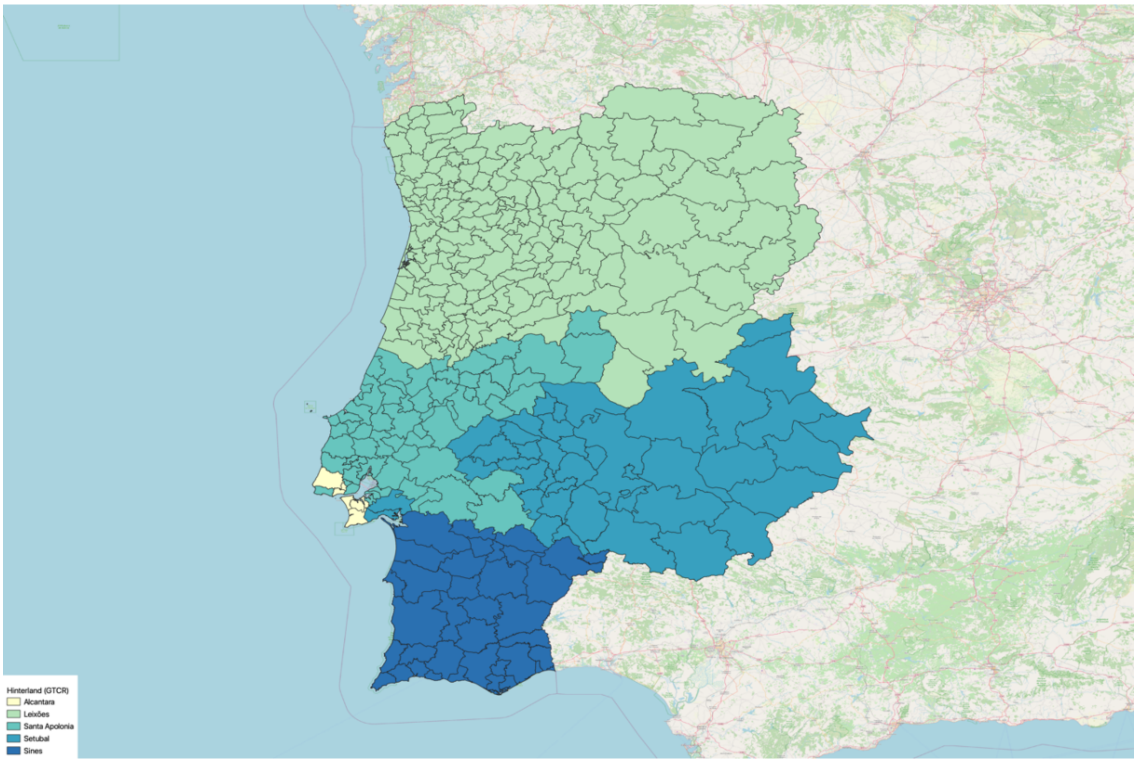


Figure 36: Hinterland (generalized transportation cost – road only)

5.2.10. Contestability index

Figure 37 shows the contestability index per municipality and comarca. The contestability index is the number of terminals for each municipality and comarca that have a generalized transportation cost within 25% of the most competitive terminal. This was determined for each municipally and comarca, being possible to observe that the Port of Leixões has a clear generalized transportation cost advantage in the municipalities in the north of Portugal and in the comarcas of the provinces of Salamanca and Zamora in Spain.

As regards the rest of the Portuguese municipalities and Spanish comarcas analyzed, most of them present between 2 and 4 terminals with the generalized transportation cost within 25% of the most competitive terminal, which means a significant competition between these terminals.

In most comarcas of the province of Caceres and in some Portuguese municipalities close to the border between Portugal and Spain in the region of this same province, there is an even higher contestability index, indicating that any of the 5 terminals analyzed in this thesis are competitive in these locations. Finally, the Port of Sines has no significant competition in the municipalities of Sines and Odemira, in the south of Portugal, because of their proximity to the terminal.

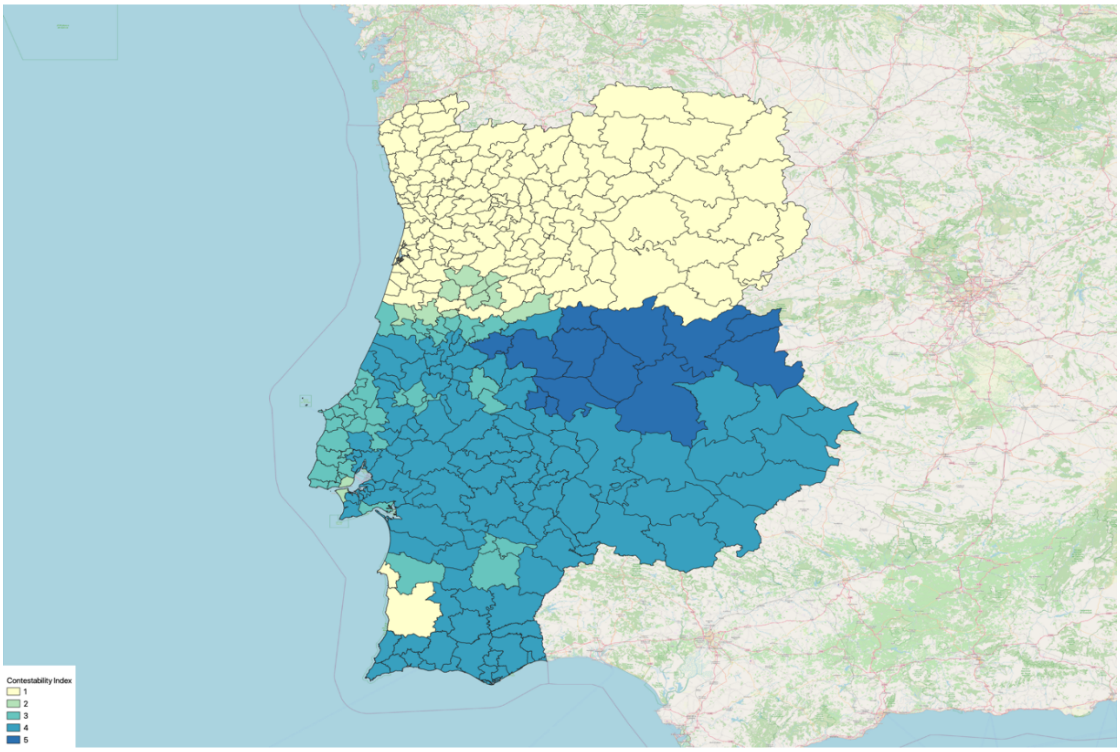


Figure 37: Contestability index

5.3. Rail and road transportation

In this second phase of analysis, 5 different combinations of road and rail paths, only to Terminal XXI in the port of Sines, were considered and then compared to the road option, in order to determine the influence of railways in the transportation cost, transportation time and in the GTC. Therefore, rail transport of containers will be added as an alternative option to the port of Sines. In any case, the containers are first carried to these intermodal terminals, loaded in the trains and carried by rail to Sines.

This scenario closely resembles the existing reality as trains currently go to Sines from intermodal terminals in Bobadela (node 173), Entroncamento (node 251), Praias do Sado (node 581), Leixões (node 544) and Valongo (node 756). Consequently, paths have been added in the data file, identified respectively as 7, 7A, 7B, 7C and 7D. The same maps presented in the previous section of this thesis will now be presented considering these new paths. The black dots in Figure 38 represent these 5 terminals.

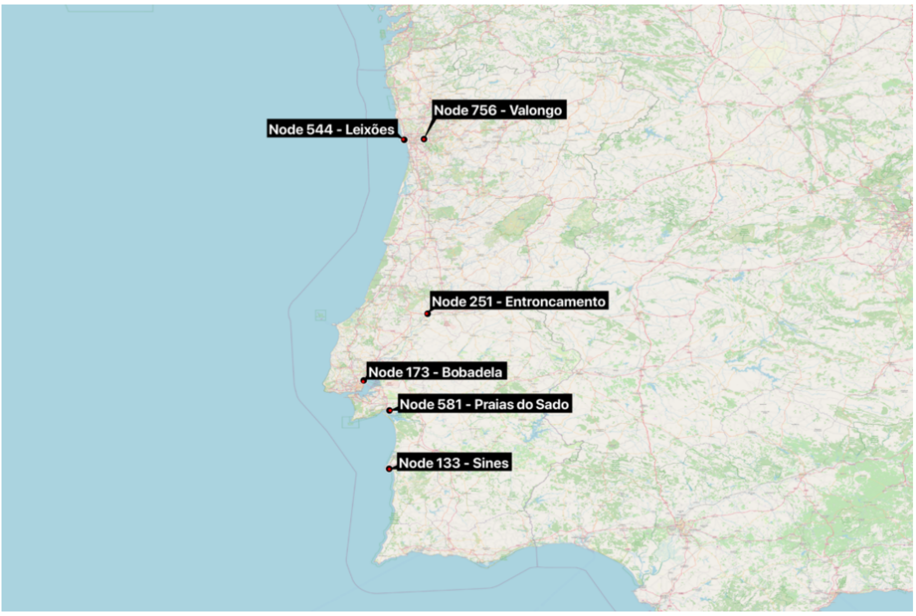


Figure 38: Intermodal terminals

5.3.1. Minimum transportation cost

Figure 39 shows the minimum transportation cost (in euros), when considering a combination of road and rail transportation to the Port of Sines, presenting lower values for municipalities in the center and south of Portugal and higher values for Portuguese municipalities in the north of the country and most of the comarcas of the analyzed Spanish provinces.

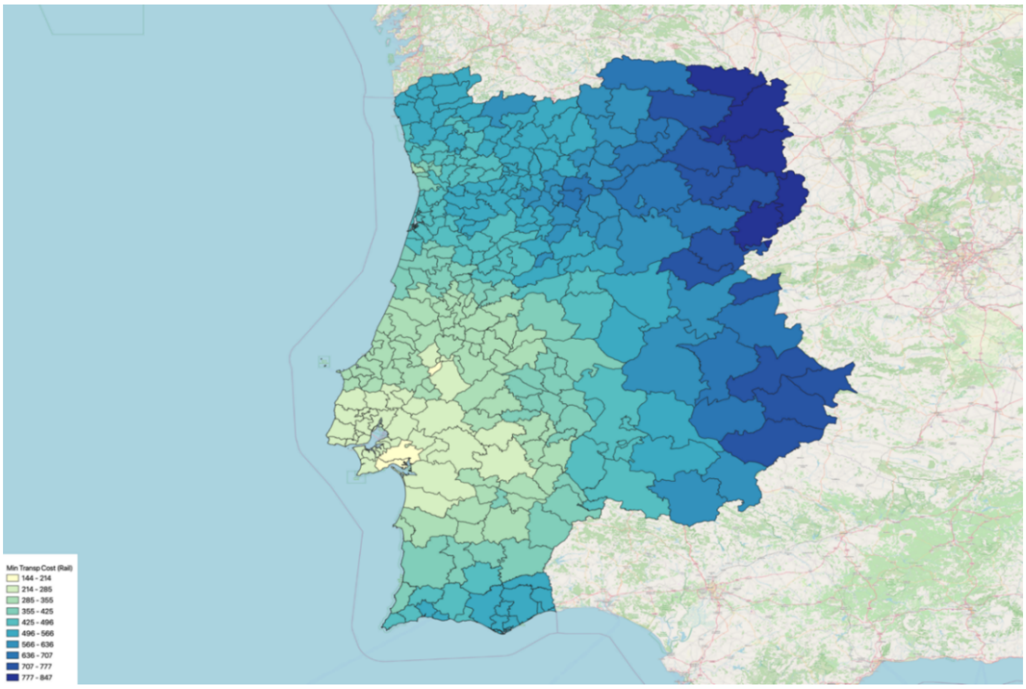


Figure 39: Minimum transportation cost (road + rail)

If the combination of road and rail is the one chosen in the transportation to the Port of Sines, path 7B presents the lowest transportation costs in most Portuguese municipalities located in the region of Algarve, Alentejo and in the Lisbon metropolitan area and in the Spanish comarcas of the province of Badajoz and some in the province of Caceres.

Path 7 should be used only in the municipalities of Lisboa, Odivelas and Loures and path 7C in some Portuguese municipalities close to Porto, Braga and Viana do Castelo. Finally, path 7D is the best option when considering the transportation cost in the comarcas of the Spanish province of Zamora and in some municipalities in Bragança and Vila Real in Portugal, and path 7C has lower transportation costs in the center of Portugal and in most Spanish comarcas of the province of Salamanca and some comarcas in Caceres. This results can be seen in Figure 40.

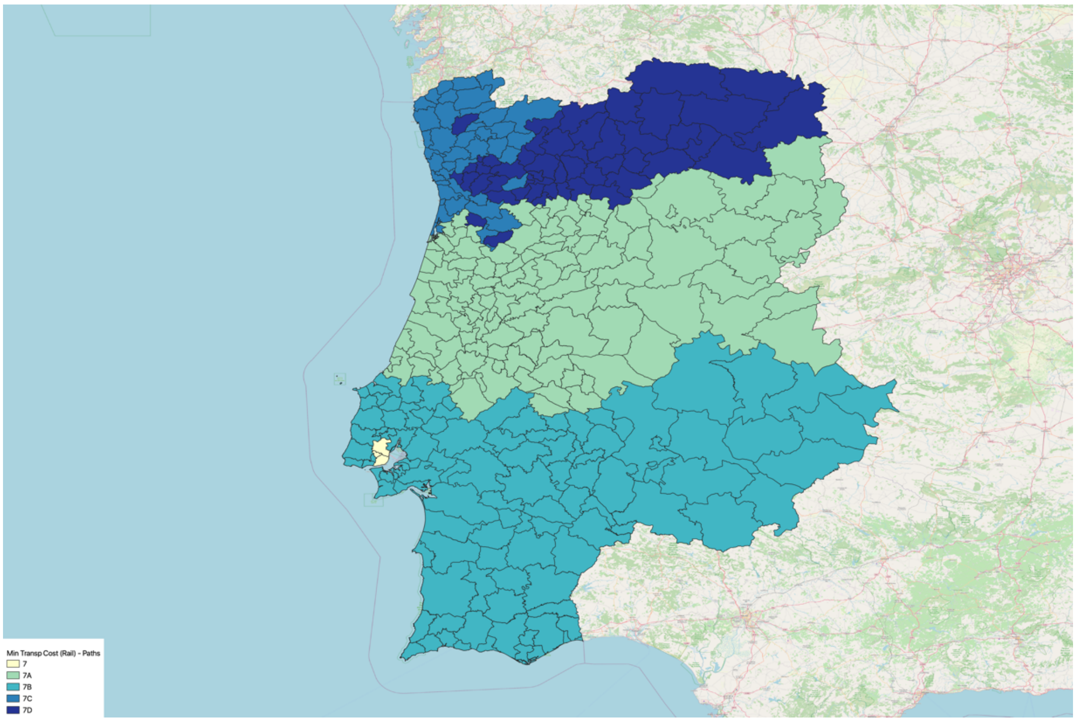


Figure 40: Optimum paths considering the transportation cost (road + rail)

5.3.2. Minimum transportation time

Very similar to what happens when analyzing the transportation cost of the multimodal transportation to the Port of Sines, Figure 41 shows the transportation time when considering a combination of road and rail transportation, which presents lower values for municipalities in the center and south of Portugal and higher values for Portuguese municipalities in the north of the country and most of the comarcas of the analyzed Spanish provinces.

In this case, it is also possible to observe that the minimum transportation times to the Port of Sines are seen in some municipalities in the Lisbon metropolitan area and close to Setúbal.

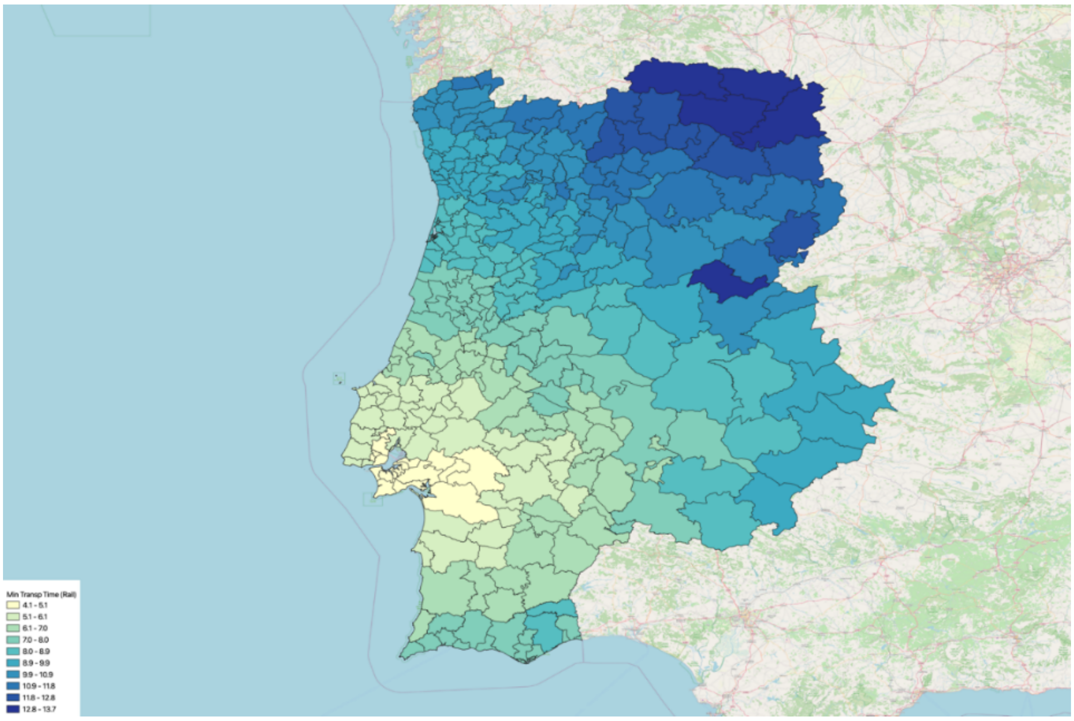


Figure 41: Minimum transportation time (road + rail)

If the combination of road and rail is the one chosen in the transportation to the Port of Sines, path 7B presents the lowest transportation times in all Portuguese municipalities and Spanish comarcas analyzed in this thesis.

Although, as it will be pointed further in this report when comparing the transportation times between road only and multimodal transportation, the second option is not competitive at all when considering only this criteria, because of the much higher transportation times using the paths combining road and rail modes. This results can be seen in Figure 42.

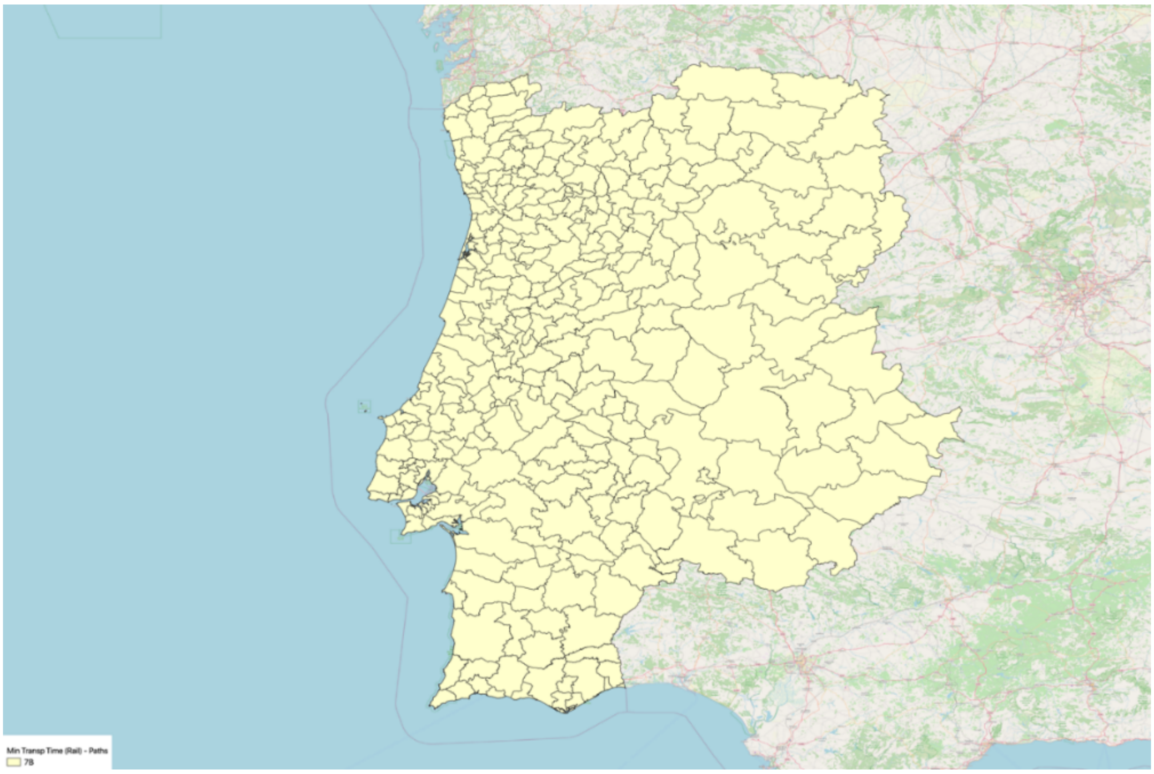


Figure 42: Optimum paths considering the transportation time (road + rail)

5.3.3. Minimum generalized transportation cost

Again, when considering a combination of road and rail transport to the Port of Sines, it is possible to observe in Figure 43 similarities between the minimum generalized transportation cost distribution and the transportation cost and transportation time for the same paths. The map presents lower values for municipalities in the center and south of Portugal and higher values for Portuguese municipalities in the north of the country and most of the comarcas of the analyzed Spanish provinces.

The minimum generalized transportation costs to the Port of Sines are seen in some municipalities in the Lisbon metropolitan area and close to Setúbal, and in this case also in in the municipalities of Golegã, Torres Novas, Entroncamento and Vila Nova da Barquinha, in the center region of Portugal.

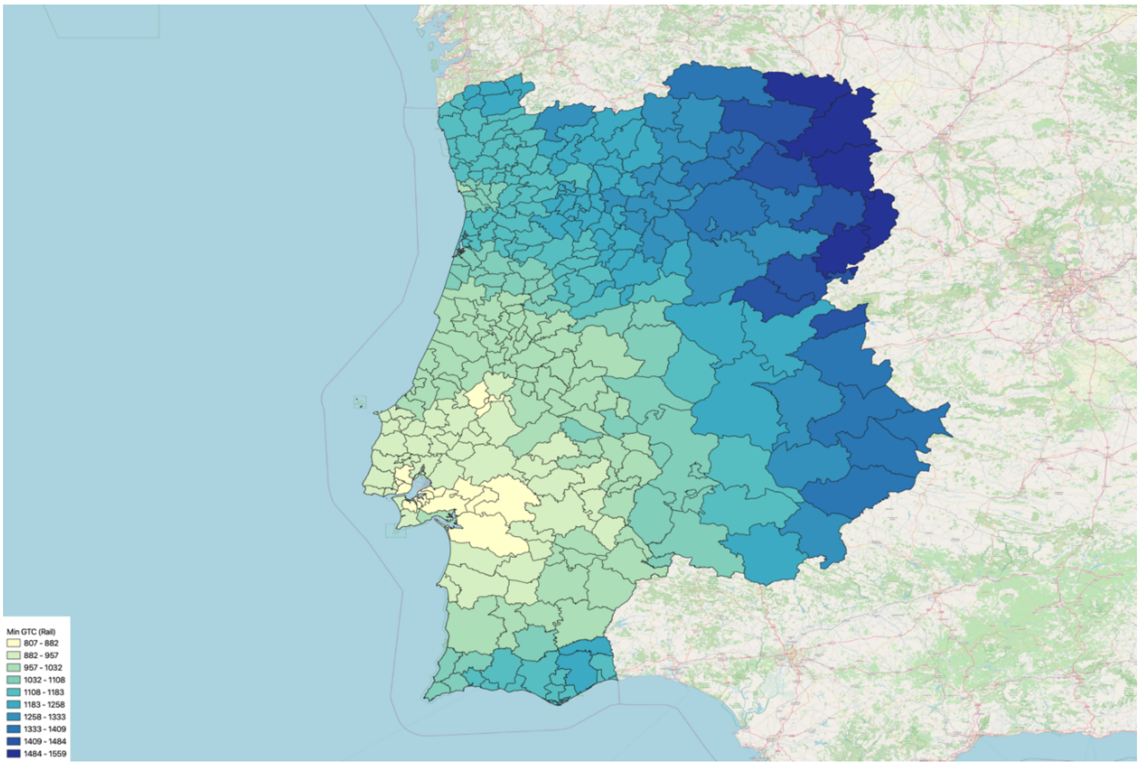


Figure 43: Minimum generalized transportation cost (road + rail)

Figure 44 shows the optimum paths using road and rail transportation to the Port of Sines considering the generalized transportation cost, which are the same for most of the analyzed Portuguese municipalities and Spanish comarcas as the ones presented in Figure 369, where only the transportation cost was taken into consideration.

Some differences are that in this case, the optimum path for the municipality of Setúbal is path 7 instead of 7B, Alter do Chão should use path 7B instead of 7A and the municipalities of Murtosa, Ovar, Santa Maria da Feira, Vale de Cambra, Oliveira de Frades, Vouzela, São Pedro do Sul, Lamego, Tarouca and Vila Nova de Foz Côa, all in the north of Portugal, have path 7A as the optimum one instead of 7C or 7D when only the transportation cost was considered.

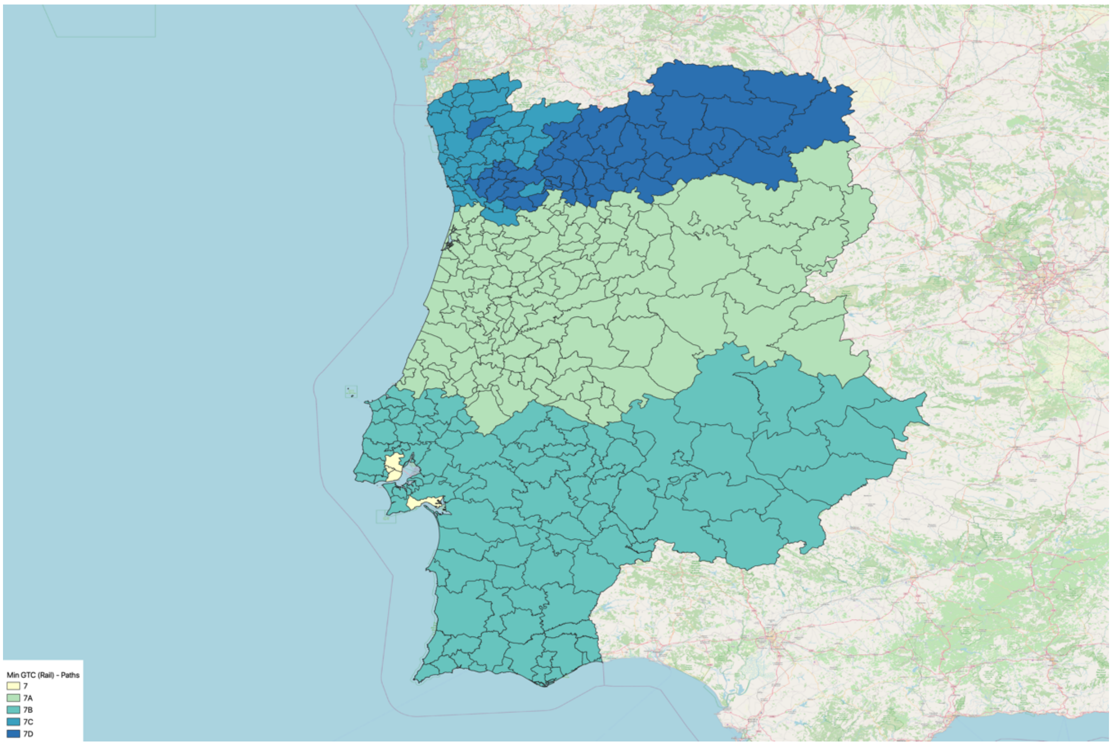


Figure 44: Optimum paths considering the generalized transportation cost (road + rail)

5.3.4. Contestability index

Figure 45 shows the contestability index, which compares all 5 analyzed paths considering the minimum generalized transportation cost and determines, for each municipality and comarca, how many of them have this value within 25% of the most competitive one.

From the map shown in Figure 45, it is possible to observe that in most municipalities in the south and center of Portugal and most comarcas from the provinces of Badajoz and Caceres, there are 3 intermodal paths with the generalized transportation cost within the 25% range of the most competitive one. This also happens in some Portuguese municipalities in the extreme north of the country and also in some comarcas from the province of Zamora.

There is also another region where all 5 paths analyzed are competitive when considering only the generalized transportation cost. This area comprehends the north of Portugal and extends to most comarcas from the provinces of Zamora and Salamanca.

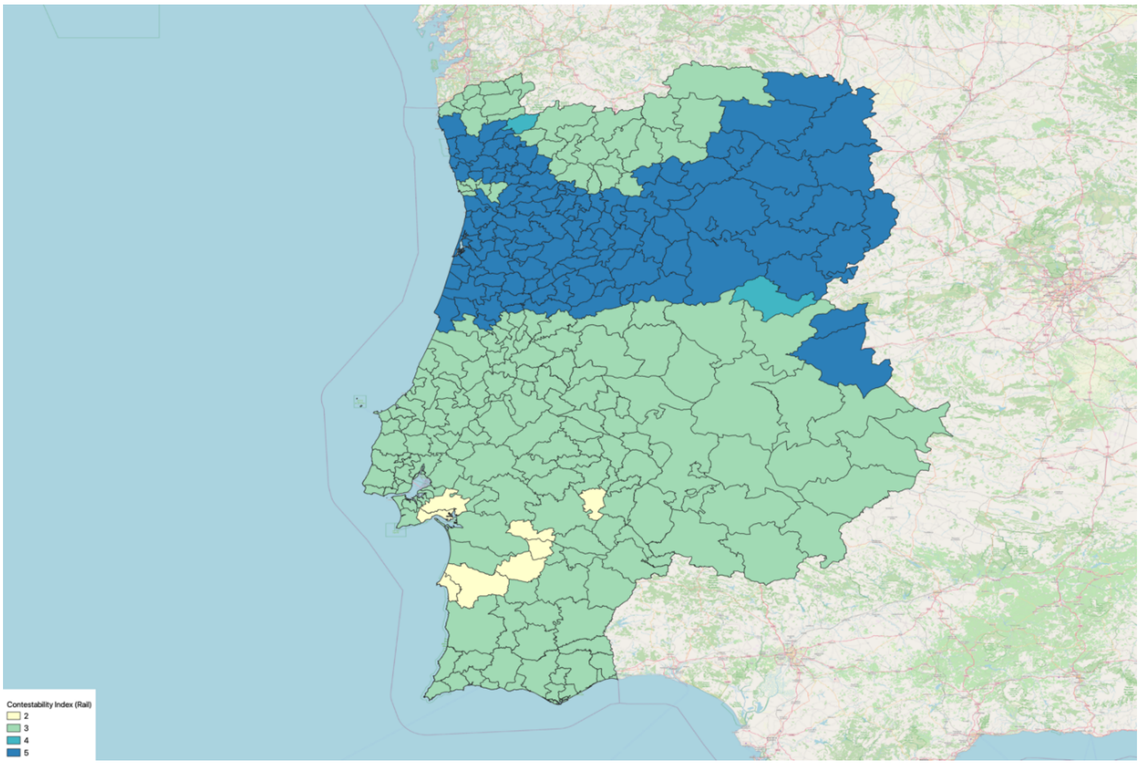


Figure 45: Contestability index between the analyzed paths (road + rail)

5.4. Comparison between road only and road + rail transportation - Sines

In order to verify which type of transportation (road only or road + rail) is best in each municipality in Portugal and comarca in the provinces of Badajoz, Caceres, Salamanca and Zamora in Spain, when considering Terminal XXI in the port of Sines as a final destination, the results for minimum transportation cost, minimum transportation time and minimum generalized transportation cost for these two different transportation options were compared and it was determined where to use road only transportation and where to use road + rail transportation.

At last, in the municipalities and comarcas where road + rail transportation was considered to be the best option, the savings regarding transportation cost, transportation time and generalized transportation cost when compared to road only transportation were also determined.

5.4.1. Transportation cost

Figure 46 shows the municipalities and comarcas for which it is preferable to use road only transportation or road + rail transportation, considering as criterion the transportation cost. It is possible to see that, when considering the transportation costs to the port of Sines, the combination of road and rail transportation is the best choice for all of the Spanish comarcas in the provinces of Badajoz, Caceres, Salamanca and Zamora, and also in all Portuguese municipalities located in the north of the country and most in the center and in the Lisbon metropolitan area.

For most of the Portuguese municipalities in the south of the country and some in the Lisbon metropolitan area, road only transportation should be used. This can be explained because rail transportation gets more competitive over road only transportation for longer distances. This way, it is not worth it to use the combination of road and rail modes for Portuguese municipalities located not far from the Port of Sines.

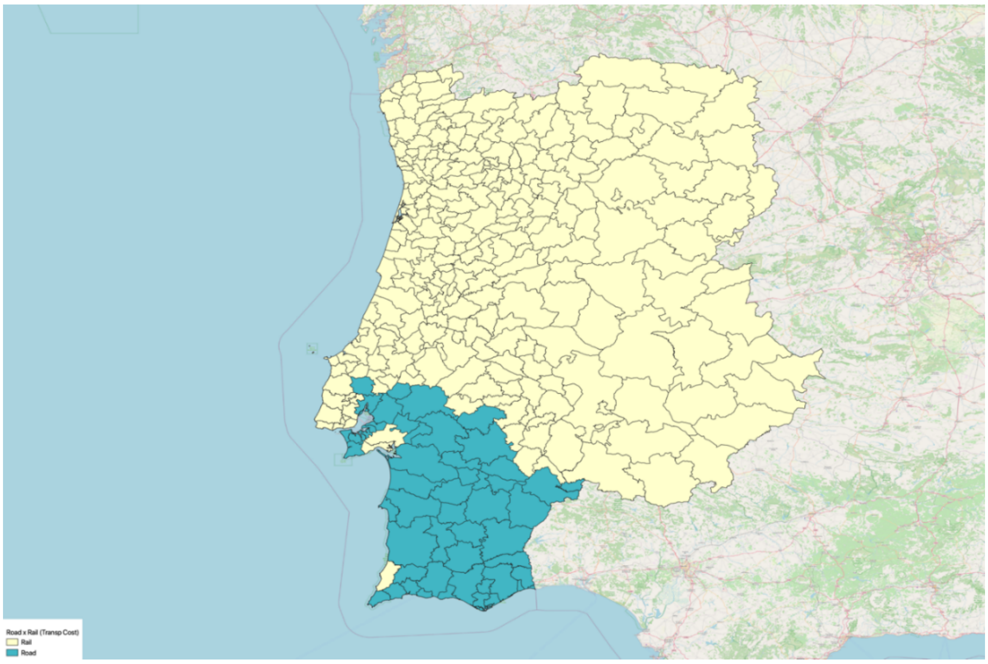


Figure 46: Road only transportation vs road + rail transportation hinterlands considering the transportation costs

Figure 47 shows the savings, in Euros, in the transportation cost when using the combination of road and rail transportation when compared to the road only transportation costs.

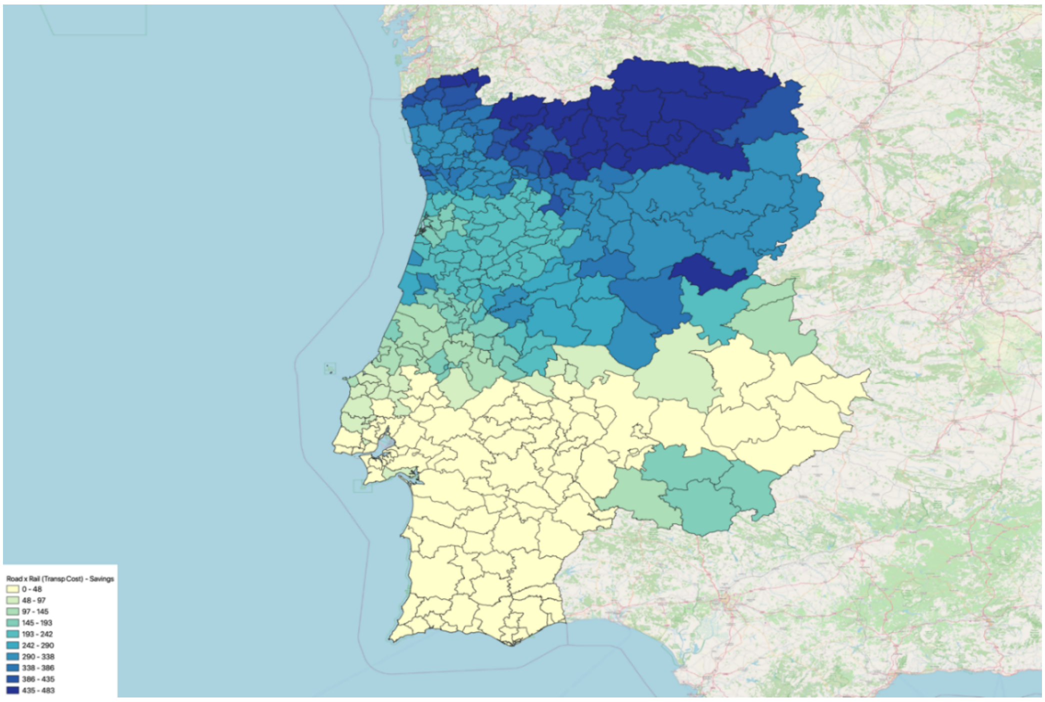


Figure 47: Road + rail transportation costs savings compared to road only transportation costs

It is possible to identify that the highest savings in the transportation costs to the port of Sines are observed in Portuguese municipalities in the north of the country and in Spanish comarcas located in the provinces of Zamora and Salamanca. Savings can go up to almost 500 euros. The savings are of approximately 300 euros in the coastal area around Porto and rise to 450 euros further inland closer to the Spanish border (Bragança). These results were to be expected, as rail transportation is more competitive over road only transportation in longer distances.

5.4.2. Transportation time

Figure 48 shows the municipalities and comarcas preferring road or road + rail transportation, when considering only the transportation time as a criterion. Road only transportation should be used in all Portuguese municipalities and Spanish comarcas analyzed, as cargo trains take longer than a truck to travel a same distance. This way, when considering only the transportation time, there are no savings for any of the Portuguese municipalities and Spanish comarcas analyzed.

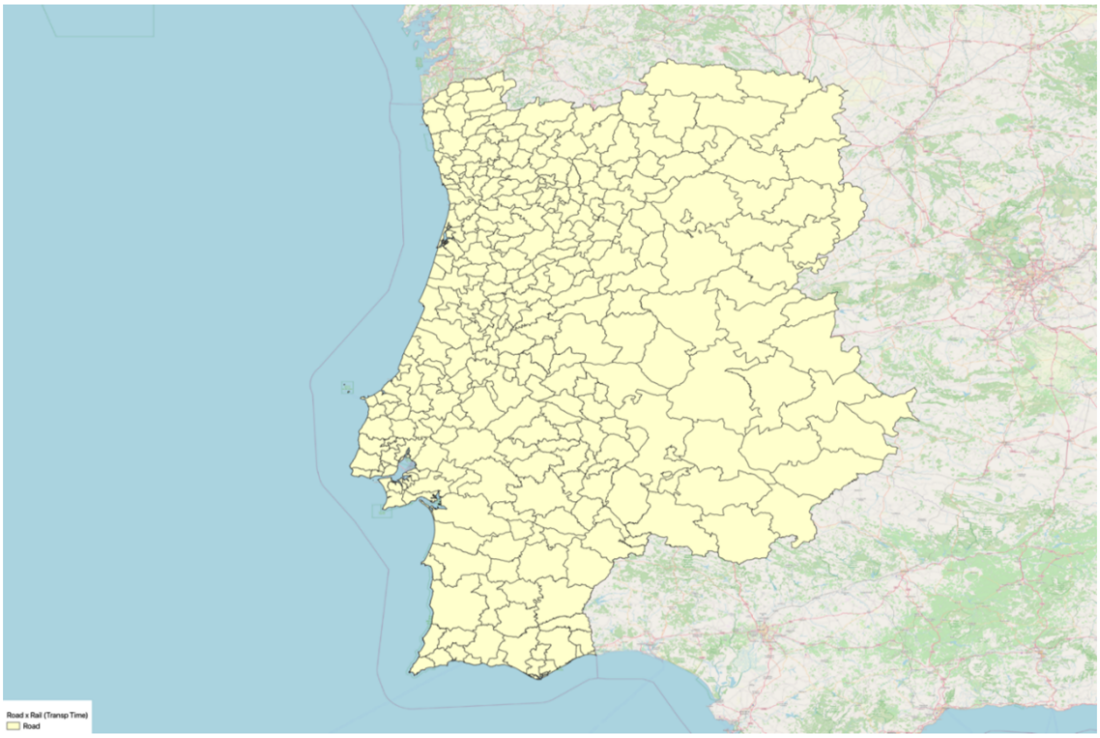


Figure 48: Road only transportation vs road + rail transportation hinterland considering the transportation time

5.4.3. Generalized transportation cost

Figure 49 shows the municipalities and comarcas for which it is preferable to use road transportation or road + rail transportation. It is possible to see that, when considering the generalized transportation costs to the Port of Sines, the combination of road and rail transportation is the best choice for most of the Spanish comarcas in the provinces of Caceres, Salamanca and Zamora, and also in all Portuguese municipalities located in the north of the country and some in the center of Portugal. For most of the Portuguese municipalities in the south of the country, in the Lisbon metropolitan area and some in the center of the country, and also most of the comarcas in the provinces of Caceres and Badajoz road only transportation should be used. This is because GTC includes the effect of transit time, and as road transport is faster, this effect is visible in an increase of the area attracted to road transport in comparison with Figure 45.

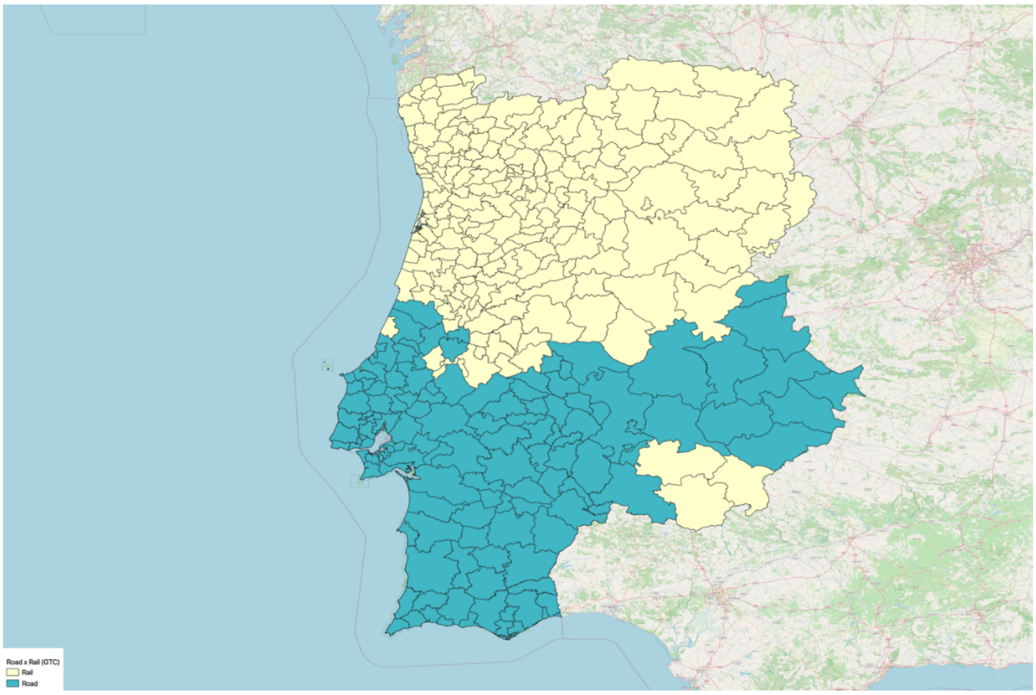


Figure 49: Road only transportation vs road + rail transportation hinterlands considering the generalized transportation cost

Figure 50 shows the savings in GTC (in Euros) offered by having an intermodal transport option in operation (road + rail) and in competition with road based transportation. It is worth reminding that the rail option is always directed to the terminal in Sines.

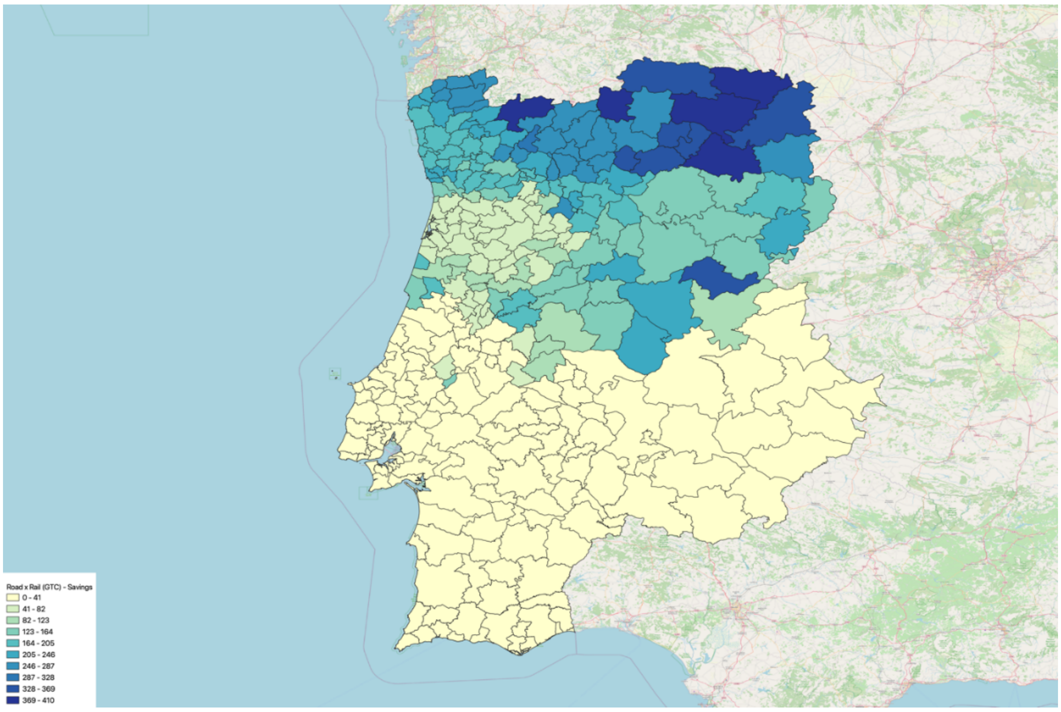


Figure 50: Road + rail generalized transportation cost savings compared to road only generalized transportation cost

In this figure it is possible to identify that the highest savings in the transportation costs to the port of Sines are observed in Portuguese municipalities in the north of the country and in Spanish comarcas located in the provinces of Zamora and Salamanca. This results were to be expected, as rail transportation is more competitive over road only for transportation in longer distances. In general, for all locations north of Coimbra, Castelo Branco and northern Extremadura, there are savings to be made when using intermodal transportation, up to values of about 400 euros. However, these savings are less significant than was the case in Figure 46.

5.5. Comparison between road only and road + rail transportation – overall

The results from the first and second phases of analysis will be compared, in order to determine if having the option to transport cargo to the port of Sines using a combination of road and rail modes impacts the main inland hinterlands of the terminals.

5.5.1. Transportation cost

Figure 51 shows the hinterlands considering the transportation cost. It can be seen that in this case, for some Portuguese municipalities in the center of the country, close to the border with Spain, as well as some comarcas in the provinces of Badajoz, Caceres and Salamanca, it is better to transport cargo to the port of Sines using a combination of road and rail modes. Also, the Portuguese municipalities of Entroncamento, Golegã in the Alentejo region, and Aljezur in Algarve should use this intermodal option to transport its cargo. Other than that, the hinterlands are similar to the ones when considering road only transportation.

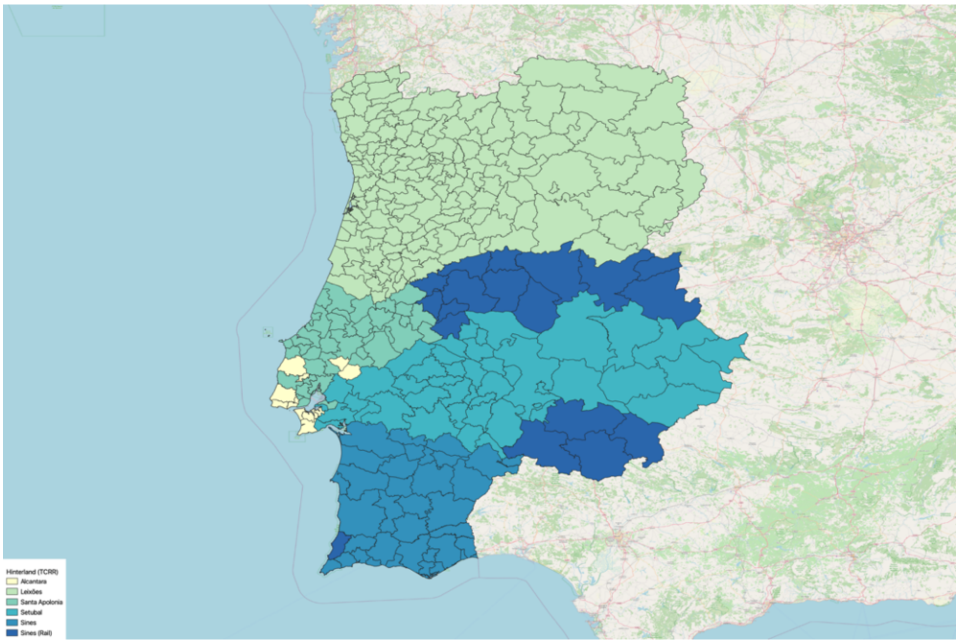


Figure 51: Hinterlands when considering road only and road + rail transportation (as per transportation cost)

5.5.2. Transportation time

As for the transportation time, there are no changes in the hinterlands when considering road only transportation or when including the intermodal option, because the transportation times using railways are much higher than the ones using roads. These results can be seen in the map shown in Figure 52.

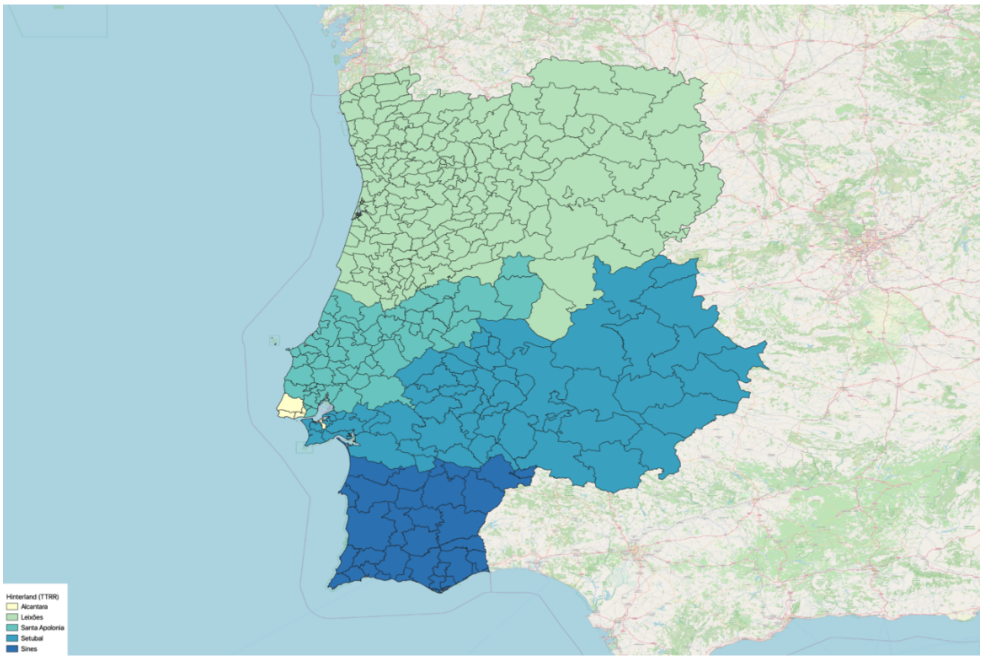


Figure 52: Hinterlands when considering road only and road + rail transportation (as per transportation time)

5.5.3. Generalized transportation cost

As for the GTC, there are also no changes in the hinterlands when considering road only transportation or when including the intermodal option. This occurs because transporting cargo by rail is economically viable for longer distances, which is not the case in the region analyzed. In this case, the distances between the Portuguese municipalities and Spanish comarcas to any of the analyzed terminals range from short to medium, in which road transportation is overall cheaper than rail transportation. These results can be seen in Figure 53.

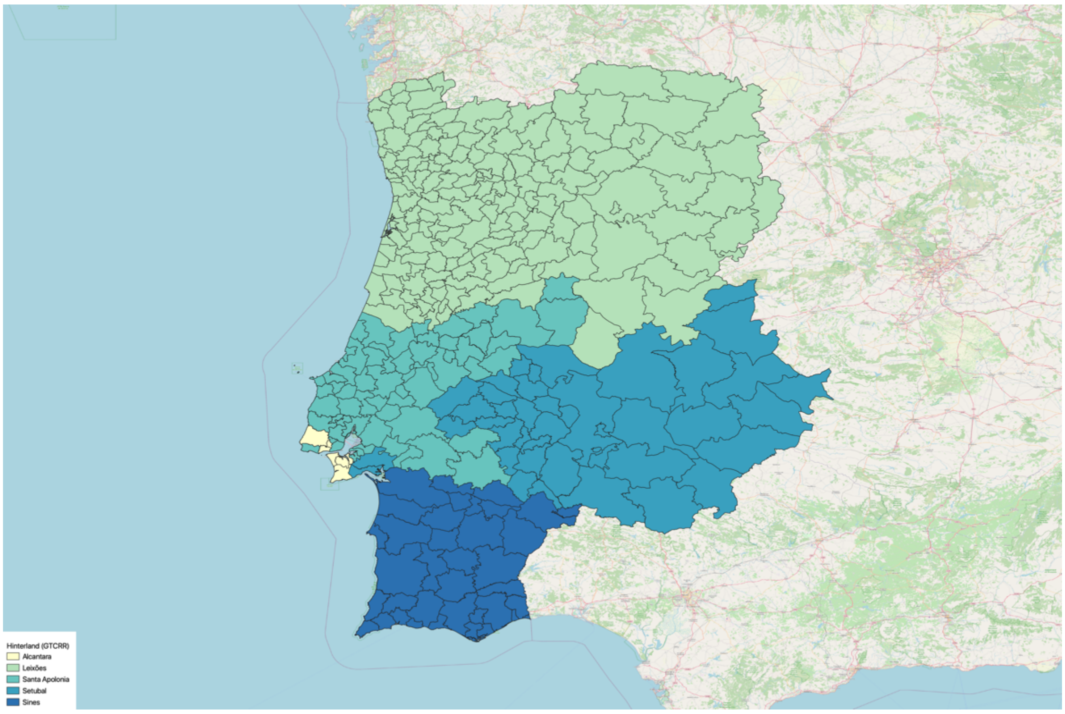


Figure 53: Hinterlands when considering road only and road + rail transportation (as per GTC)

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

As the dynamic of the world economy changed over the last decades, nowadays the economic influence of a seaport depends not only on the distance, but mainly on the effectiveness of its hinterland connections. In order to improve the competition level of a seaport, intermodal transport is being used to make the best of the transportation infrastructure, giving more route options and lowering travel costs by selecting optimum carrier and vehicle combinations for each case. However, it is necessary to compare the intermodal option with road only transportation in regards of the cost, travel time and in how this choice helps improve the hinterland of the port itself.

In this context, a hinterland characterization of the main container terminals in Portugal was made using QGIS, which allows a good visualization of the impact intermodal transport has in the hinterland influence of a terminal when compared to road only transportation. This hinterland characterization with QGIS was based on data provided by Intermodal Analyst, a software developed in the research unit CENTEC of IST, University of Lisbon, that calculates the cost and time of transport between an origin and a destination, across a transport network comprising various modes of transportation.

A set of transportation nodes covering all Portuguese municipalities and Spanish comarcas in the provinces of Badajoz, Caceres, Salamanca and Zamora was selected and the terminals considered in this project were Leixões (TCL), Lisbon (Liscont, in Alcântara, and Sotagus, in Santa Apolónia), Setúbal (Sadoport) and Sines (Terminal XXI). The hinterland of these terminals when considering road only transportation was analyzed with regard to the transportation cost, transportation time and generalized transportation cost (GTC). After that, an intermodal option of rail + road transport was considered only for the terminal of Sines, as the other terminals receive relatively few containers by railway. Also, a contestability index was calculated in order to evaluate the level of competition between the analyzed terminals in function of the GTC.

In the first phase of analysis, in which intermodal transport was not considered, it was possible to observe that the hinterland of the terminal of Sines and the hinterland of the terminal of Leixões did not present any significant changes between the analyzed criteria. As for the terminal of Setúbal, when considering the GTC, it did lose part of its hinterland in Alentejo Central to the Santa Apolónia terminal when compared to its hinterland regarding the transportation time and transportation cost. The Alcântara terminal presents a hinterland composed mainly of municipalities located in the Lisbon metropolitan area in all cases. In a scenario in which the generalized transportation cost is the decisive criteria, the terminal of Leixões has the largest hinterland, while the terminals of Sines, Setúbal and the Santa Apolónia present hinterlands with approximately the same area, and the terminal of Alcântara has a hinterland composed of only 7 municipalities in the Lisbon metropolitan area. However, the numerical results for the Alcântara and Santa Apolónia (both in Lisbon) are very similar and their hinterlands largely overlap.

As for the second phase, considering an intermodal option along with road only transportation to the terminal of Sines, in regards of transportation cost the combination of road and rail is the best choice for all of the Spanish comarcas analyzed and also in all Portuguese municipalities located in the north of the country and most in the center and in the Lisbon metropolitan area. This happens because rail transportation gets more competitive over road only for transportation for longer distances. When the transportation time is taken into consideration, there is no doubt that intermodal transport is not an option, as cargo trains take longer than a truck to travel a same distance. Finally, when considering the GTC to the terminal of Sines, the combination of road and rail transportation is the best choice for most of the Spanish comarcas in the provinces of Caceres, Salamanca and Zamora, and also in all Portuguese municipalities located in the north of the country and some in the center of Portugal.

Finally, the results from the first and second phases of analysis were compared, in order to determine if having the option to transport cargo to the port of Sines using a combination of road and rail modes impacts the main inland hinterlands of the terminals. It was possible to observe that having an intermodal option resulted only in a small change in the terminals' hinterlands regarding the transportation cost. Other than that, when transportation time or GTC is to be considered, road transportation is still the best choice for the analyzed scenario. Notwithstanding these facts, it was observed that intermodal transport (road and rail) did reduce transport costs to Sines, even if not sufficiently to attract a significant number of municipalities to the hinterland of the Sines container terminal.

6.2 Recommendations for further work

The next step of this study should be including container terminals in Spain and expanding the analyzed area to other regions of Spain, in order to have more comprehensive and detailed results for the hinterland of Portuguese container terminals, therefore establishing the real economic influence of the main Portuguese ports. It is also important to develop, keep up to date and document the transport network database.

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ANNEX A – NODES CORRESPONDING TO MUNICIPALITIES IN PORTUGAL

NODE	MUNICIPALITY
46	Almada
47	Sesimbra
51	Palmela
52	Seixal
53	Barreiro
57	Moita
58	Montijo
59	Alcochete
62	Mafra
64	Sintra
65	Cascais
67	Arruda dos Vinhos
68	Sobral de Monte Agraço
71	Torres Vedras
72	Vila Franca de Xira
74	Loures
78	Alenquer
79	Azambuja
80	Salvaterra de Magos
81	Benavente
84	Montijo
87	Setúbal
88	Vendas Novas
91	Coruche
92	Oeiras
93	Lisboa
101	Odivelas
109	Amadora
110	Cartaxo
114	Montemor-o-Novo
116	Alcácer do Sal
127	Santiago do Cacém
129	Odemira
130	Ferreira do Alentejo
132	Sines
134	Grândola
135	Aljustrel
138	Almeirim
139	Santarém
145	Rio Maior
149	Óbidos
151	Peniche

152	Lourinhã
155	Bombarral
156	Cadaval
158	Caldas da Rainha
160	Alcobaça
161	Nazaré
162	Marinha Grande
165	Leiria
168	Batalha
169	Porto de Mós
172	Ourém
173	Tomar
176	Ferreira do Zêzere
179	Entroncamento
181	Torres Novas
184	Golegã
185	Chamusca
186	Alpiarça
187	Alcanena
189	Constância
190	Vila Nova da Barquinha
192	Abrantes
193	Sardoal
195	Alvaiázere
197	Pombal
206	Figueira da Foz
210	Montemor-o-Velho
212	Soure
213	Penela
217	Ansião
218	Figueiró dos Vinhos
220	Castanheira de Pêra
221	Pedrógão Grande
222	Condeixa-a-Nova
225	Miranda do Corvo
226	Lousã
230	Coimbra
243	Elvas
249	Évora
250	Arraiolos
252	Mora
253	Viana do Alentejo
254	Alvito
255	Ponte de Sôr
256	Avis
257	Estremoz
258	Sousel
260	Fronteira
261	Monforte

262	Alter do Chão
263	Crato
264	Portalegre
265	Arronches
267	Campo Maior
269	Mação
270	Gavião
273	Nisa
275	Vila Velha de Ródão
276	Castelo de Vide
277	Marvão
285	Borba
286	Vila Viçosa
287	Alandroal
288	Redondo
309	Mourão
310	Reguengos de Monsaraz
311	Vila de Rei
312	Sertã
313	Proença-a-Nova
314	Portel
315	Cuba
316	Vidigueira
317	Moura
318	Barrancos
319	Serpa
320	Beja
321	Mértola
322	Castro Verde
323	Ourique
324	Almodôvar
333	Castelo Branco
337	Idanha-a-Nova
339	Oleiros
341	Pampilhosa da Serra
343	Góis
345	Vila Nova de Poiares
346	Penacova
348	Tábua
349	Mortágua
350	Santa Comba Dão
352	Arganil
353	Carregal do Sal
354	Mira
355	Cantanhede
357	Mealhada
358	Tondela
359	Oliveira do Hospital
361	Covilhã

362	Penamacor
365	Seia
366	Nelas
367	Anadia
368	Oliveira do Bairro
371	Vagos
373	Águeda
375	Mangualde
378	Fornos de Algodres
380	Celorico da Beira
382	Guarda
384	Sabugal
386	Belmonte
387	Manteigas
388	Gouveia
389	Penalva do Castelo
391	Viseu
397	Ílhavo
400	Aveiro
409	Estarreja
410	Murtosa
412	Albergaria-a-Velha
413	Sever do Vouga
414	Oliveira de Frades
415	Vouzela
416	São Pedro do Sul
417	Sátão
419	Almeida
420	Pinhel
421	Trancoso
422	Aguiar da Beira
423	Vila Nova de Paiva
425	Castro Daire
426	Vale de Cambra
428	Oliveira de Azeméis
431	Arouca
432	São João da Madeira
434	Ovar
435	Santa Maria da Feira
437	Espinho
442	Castelo de Paiva
443	Cinfães
444	Resende
445	Lamego
447	Tarouca
448	Moimenta da Beira
450	Sernancelhe
451	Penedono
452	Mêda

454	Figueira de Castelo Rodrigo
455	Freixo de Espada à Cinta
456	Torre de Moncorvo
458	São João da Pesqueira
459	Tabuaço
460	Armamar
463	Peso da Régua
464	Mesão Frio
465	Santa Marta de Penaguião
467	Vila Real
469	Sabrosa
470	Alijó
471	Carrazeda de Ansiães
472	Vila Flor
474	Alfândega da Fé
476	Mogadouro
479	Murça
481	Mirandela
482	Macedo de Cavaleiros
486	Vimioso
487	Miranda do Douro
488	Mondim de Basto
490	Cabeceiras de Basto
491	Ribeira de Pena
494	Vila Pouca de Aguiar
495	Valpaços
499	Bragança
501	Chaves
503	Boticas
505	Montalegre
506	Vila Nova de Foz Côa
511	Vinhais
512	Fundão
517	Amarante
518	Baião
519	Marco de Canaveses
522	Penafiel
524	Paredes
527	Valongo
529	Gondomar
537	Vila Nova de Gaia
538	Porto
543	Maia
549	Paços de Ferreira
550	Lousada
553	Felgueiras
555	Vizela
558	Braga
561	Santo Tirso

563	Trofa
565	Vila Nova de Famalicão
567	Vila do Conde
569	Póvoa de Varzim
573	Barcelos
575	Esposende
585	Amares
586	Terras de Bouro
587	Vila Verde
589	Ponte de Lima
591	Vieira do Minho
593	Celorico de Basto
596	Viana do Castelo
598	Caminha
599	Vila Nova de Cerveira
601	Paredes de Coura
603	Ponte da Barca
604	Arcos de Valdevez
606	Valença
608	Monção
609	Melgaço
611	Fafe
612	Braga
614	Póvoa de Lanhoso
747	Alcoutim
751	Castro Marim
752	Vila Real de Santo António
753	Alcoutim
755	Olhão
756	Faro
758	São Brás de Alportel
760	Loulé
763	Albufeira
765	Silves
767	Lagoa
769	Portimão
770	Monchique
771	Lagos
775	Vila do Bispo
776	Aljezur
777	Vila Real de Santo António
2518	Matosinhos

ANNEX B – NODES CORRESPONDING TO COMARCAS IN SPAIN (EXTREMADURA AND CASTILLA Y LEON)

NODE	COMARCA
279	VALENCIA DE ALCÂNTARA
280	ALBURQUERQUE
281	OLIVENZA
284	BADAJOZ
289	MERIDA
290	DON BENITO
292	CACERES
294	ALMENDRALEJO
295	JEREZ DE LOS CABALLEROS
298	LLERENA
299	CASTUERA
300	PUEBLA ALCOCER
301	LOGROSAN
302	TRUJILLO
303	NAVALMORAL DE LA MATA
304	PLASENCIA
305	CORIA
308	BROZAS
659	CIUDAD RODRIGO
663	FUENTE DE SAN ESTEBAN
664	VITIGUDINO
669	LEDESMA
674	LA SIERRA
678	ALBA DE TORMES
682	SALAMANCA
692	PEÑARANDA DE BRACAMONTE
695	SAYAGO
698	DUERO BAJO
712	CAMPOS-PAN
714	ALISTE
719	BENAVENTE Y LOS VALLES
724	HERVAS
725	SANABRIA
2879	AZUAGA
2880	HERRERA DUQUE
2881	JARAIZ DE LA VERA